Mathematical Instrumentation in Fourteenth-Century Egypt and Syria: The Illustrated Treatise of Najm al-Din al-Misri

François Charette

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MATHEMATICAL INSTRUMENTATION IN FOURTEENTH-CENTURY EGYPT AND SYRIA

The Illustrated Treatise of Najm al-Dīn al-Mīṣrī

BY

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FOREWORD

This book contains the edition of an anonymous fourteenth-century Mamluk treatise on the construction of astronomical instruments, which I have attributed to Najm al-Dīn al-Miṣrī. The work is remarkable for two reasons: first, it gives construction procedures for over one hundred different instruments (mostly astrolabes, quadrants and sundials), a great number of which were previously unknown to specialists; second, these procedures are accompanied by large diagrams of each instrument accurately drawn to scale. No justification needs to be given for publishing such a technical work from fourteenth-century Egypt, as there exist several hundred scientific treatises composed in the Near East during the period *ca*. 1250–1500, out of which less than a handful have been so far edited or translated. The treatise with which the present study is concerned, even though it is atypical in many respects, still is deeply rooted within a tradition emphasising practical science, which developed in the context of Mamluk religious institutions of learning. Experts of Mamluk intellectual history have so far failed to appreciate the extent and diversity of scientific activities within these institutions. Consider the following quotation from Jonathan Berkey:

> The rational sciences – such as philosophy, logic, and mathematics – had little part in the curriculum of the schools of higher religious education in Mamluk Cairo, except, for example, in so far as a student encountered logic as an ancillary to his study of the law.[1]

It is true that Mamluk historiographical works, generally written by religious scholars, seldom provide information about teaching and research activities in astronomy or mathematics within the confines of madrasas or mosques. Yet the numerous copies of scientific treatises written or copied during the Mamluk period contain contrary evidence.[2] This claim notwithstanding, much work still needs to be done for an adequate appreciation of scientific life in Mamluk society, in particular with regard to its institutional aspects. For example, a prosopographical study of the actors, especially the *muwaqqit*s, could furthermore reveal the affiliation patterns and the genealogical network of scientific practitioners.

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[1] Berkey 1992, p. 13.
[2] For a first look at these sources see King 1983a.

I contend that a serious understanding of the Mamluk period is crucial for all historians of Islamic science, as it will inevitably lead them to examine vexing and disputable questions related to 'post-classicism' and 'decline', and to assess the complex relationship between theoretical and practical knowledge. Some of these critical issues have been perceptively addressed in an insightful essay by A. I. Sabra; commenting the phenomenon of applied science in Mamluk religious institutions, he wrote:

> ... what we have to do with here is not a general utilitarian interpretation of science, but a special view which confines scientific research to very narrow, and essentially unprogressive areas. We may rightly admire the ingenuity, inventiveness and computational prowess of the works of the *muwaqqits* on timekeeping and the *qibla*; but we have to realize that breakthroughs, if such were at all possible, could only have occurred elsewhere ...[3]

The reader will find in my introduction some evidence for my partial disagreement with Sabra's characterization of Mamluk science as 'instrumentalist' and 'unprogressive'. In general, the present book does not pursue the issues mentioned above beyond mere occasional remarks. I do hope, however, to convince readers of the following pages that a detailed social history of Mamluk science would be a worthwhile and timely undertaking.

Despite the enduring fascination for the astrolabe and its history, historians of ancient and medieval science have seldom demonstrated interest in the topic of instrumentation, which most of them see as pertaining to a category of *opera minorissima*. The study of instrumentation in Islamic civilization has never reached historiographical eminence; the outdated and incomplete character of most studies dealing with the subject is a serious hindrance. Also problematic is the fact that most of the important works from before 1300 are either unpublished or inadequately available. (The Spanish Islamic tradition, which has been thoroughly investigated by successive generations of scholars in Barcelona, is a notable exception.) This justifies the approach adopted for the commentary on Najm al-Dīn's treatise, which I have written as a self-standing historical and technical essay organised by categories of instruments. If the present publication were to foster a new interest in the subject and a more refined appreciation of its historical importance, it will have attained its goal.

I am particularly grateful to my *Doktorvater* David A. King, to whom I owe more than I could express in a few lines. His unrivalled intellectual and personal generosity, his good humour and his sagacity have been immensely helpful from the very beginning. The following persons and organisations have also provided advices and help in various ways: Hans Daiber, Lewis

[3] Sabra 1987, pp. 241–242.

Pyenson, David Pingree, Sonja Brentjes, Richard Lorch, Benno van Dalen, Kurt Maier, Ryszard Dyga and all other colleagues and friends at the Institut für Geschichte der Naturwissenschaften (Frankfurt University), the Chester Beatty Library (Dublin, Ireland), Christie's (London, UK), the Social Science and Humanities Research Council of Canada, and the Dibner Institute. This book was typeset with the system LaTeX, using macros developed by dozens of people; the Arabic text was typeset with the package ArabTeX (copyright Klaus Lagally).

I dedicate this book to my wife Iris and our two sons Kaspar and Emanuel.

Cambridge, Mass.
January 2003

Part I

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CHAPTER ONE

INTRODUCTION

Instruments are the preferred icons of science.[1] In the history of Eastern and Western art, astronomical instruments almost invariably accompany representations of astronomers and astrologers, who may be portrayed holding an astrolabe, standing next to a globe or an armillary sphere, or performing an altitude measurement through the sights of parallactic rulers or an horary quadrant. In Islamic art and literature, the astrolabe had a preeminent status, as it symbolised and embodied the science of astronomy and, perhaps even more, astrology.[2] Several representations of astronomers or astrologers can be found in Ottoman, Persian and Moghul miniatures.[3] In medieval European art we sometimes encounter astrolabes as attributes of ancient astronomers or wise men.[4] Two masterpieces of European Renaissance painting also come to mind, namely, Van Eyck's portrait of St. Jerome in his study with an astrolabe hanging in the back (1442) and Botticelli's fresco depicting St. Augustine in his study with an armillary sphere in front of him (*ca*. 1480).[5] Ancient

[1] The above statement may seem trivial: if we list, for each pre-modern or early-modern field of scientific endeavour, visual icons or symbolic attributes of the sciences, we shall inevitably end up with a list of instruments. For astronomy, the armillary sphere and the astrolabe, later the telescope; for arithmetic, the dust board or the abacus; for geometry, the compass; for geography and discoveries, the globe and the sextant. Instruments are also preeminent icons of ancient and medieval science in modern publications, as they are used to illustrate the front-page of books and journals, to adorn posters for congresses and to serve as logos for learned associations. An icon is not hard to define, but the investigation of why and how icons are used in the practice and rhetoric of ancient or modern science – or even within modern discourse on ancient science – is certainly a complex issue.

[2] See Saliba 1992, pp. 50, 53, 61 and plates 1–6.

[3] Two magnificent miniatures, one made in Shīrāz in 1410, the second one in 1596 at the royal workshop of Akbar in India, representing Naṣīr al-Dīn al-Ṭūsī and his colleagues at the Maragha observatory, are illustrated in Richard 2000, fig. 2 and fig. 4; a better reproduction of the Shīrāz miniature is in Nasr 1976, p. 22 (with misleading caption). The Ottoman miniature representing Taqī al-Dīn and his colleagues at the observatory in Istanbul is famous: see for example Sayılı 1960, Ünver 1969 (plate 2 between pp. 16 and 17 and details on plates 3–11 at the end), Nasr 1976, p. 113, or Michel 1977, p. 124. Six superb Moghul miniatures featuring astrologers at work are illustrated in Saliba 1992; on all of them an astrologer holds an astrolabe in one of his hands.

[4] See e.g. Michel 1977, pp. 97, 101, 103, or G. Turner 1991, p. 17 (the latter is a fourteenth-century miniature in Ptolemy's *Geography* showing Ptolemy holding an astrolabe). On a sundial copperplate print by Georg Hartmann we also see Ptolemy holding an astrolabe (Munich, Rara 434, unfoliated, photograph in the Ernst-Zinner-Archiv of the Institut für Geschichte der Naturwissenschaften, Frankfurt am Main).

[5] Both are illustrated in G. Turner 1991, pp. 18 and 19.

and contemporary instruments are also richly featured in frontispieces of famous seventeenth-century astronomical books, such as Kepler's *Tabulæ Rudolphinæ Astronomicæ* (1627) or Hevelius' *Uranographia* (1690).[6] The idealised representation of Tycho Brahe sitting in his observatory next to a large mural quadrant, with assistants in the background operating other instruments, is one of the best known depictions of an early modern astronomer at work.[7] When we think of astronomical instruments we generally associate them with *observations* and with astronomical practice. Historians of astronomy are indeed familiar with Ptolemy's discussion of four observational instruments (namely, the ecliptic ring, the mural quadrant, the armillary sphere and the parallactic rulers) used by him and his predecessors to gain the necessary data for establishing empirical parameters and confirming their theoretical models.[8]

Notwithstanding this iconographical tradition, the present study is mainly concerned with another category of astronomical instruments, which are labelled *mathematical* and *graphical*.[9] I look at two-dimensional objects of practical mathematics which serve as models of the heavens or as graphical devices for solving problems of positional astronomy. Also, the instruments featured in this study can be characterised as *didactical tools*. I contend in the following pages that a major function of mathematical instruments in late medieval Islamic society was indeed didactical: they were favoured visual aids used in the transmission of technical astronomical knowledge.

While having roots in the Hellenistic and – to a lesser extent – Hindu civilizations, astronomical instrumentation benefited in Islam from the formidable spirit of inventiveness and creativity that characterised all branches of theoretical and practical knowledge. Only a few decades after having adopted the astrolabe from hellenised Near Eastern centres of learning, scholars of different faiths living in *Dār al-Islām*, mainly Muslims but also Christians, Jews and others, had already improved the instrument and invented other devices that were unknown to their predecessors. Astronomical instrumentation was traditionally regarded – in encyclopædias and treatises on the classification of the sciences – as a subdivision of astronomy (*ʿilm al-nujūm*), as, for example, in the encyclopædia of the sciences by the late-tenth century Central Asian scholar Abū ʿAbd Allāh Muḥammad al-Khwārizmī.[10] Later, timekeeping joined the list as a further subdivision of astronomy; non-observational

[6] The frontispiece of J. Luyts, *Astronomica Institutio* (1692) is also of interest in this respect.

[7] Tycho Brahe, *Astronomiae Instauratae Mechanica*, 1598.

[8] Ptolemy, *Almagest*, Books I and V.

[9] I use these terms in order to emphasise their distinction from purely *observational* instruments, this despite the fact that the term 'mathematical instruments' was traditionally used in a wider sense (e.g., in seventeenth-century England). That many instruments of the mathematical genus (such as the astrolabe) were usually fitted with a pair of sights should not detract us from the fact that their main function was not to measure altitudes.

[10] al-Khwārizmī, *Mafātīḥ al-ʿulūm*, pp. 232–235. Cf. Wiedemann 1918-19, p. 2.

instrumentation, although it formed a sub-discipline of astronomy in itself, in practice often figured as an ancillary science of timekeeping. The Cairene scholar Ibn al-Akfānī (d. 739 H/1348), in his influential classification of the sciences, included timekeeping, observational instruments, the projection of the sphere and gnomonics among the subsidiary branches of astronomy.[11] During the period *ca*. 800–1100, the topic of astronomical instrumentation attracted the attention of a wide spectrum of scholars, from down-to-earth *asṭurlabī*s – those professionally concerned with the construction and operation of instruments – to universal minds like al-Bīrūnī and Ibn Sīnā,[12] and on to first-rank mathematicians,[13] court astrologers and ordinary teachers.

The focal point of the present investigation is an illustrated Arabic treatise composed in Cairo *ca*. 1330, in which the construction of over one hundred different mathematical instruments is explained. The work is anonymous but I shall later demonstrate how it can be attributed to a practical astronomer, Najm al-Dīn al-Miṣrī. This work is remarkable for several reasons, even if some of its characteristics can be considered in negative terms by traditional historiographical standards. A critical edition and translation of the treatise form the second part of what follows, and this text will provide the main source for my investigation. Before discussing the attributes of this unusual, idiosyncratic scientific production, a brief overview of its context is apposite.

1.1 *Learning and* mīqāt *in Mamluk society*

The period during which the Mamluk Sultanate ruled Egypt and Syria, namely, 1250–1517, is one of the most fascinating and colourful episodes of the medieval history of the Near East. It is also a time characterised by a remarkable level of intellectual vivacity and innovation.[14] The social transformations under Mamluk rule led to the accessibility of knowledge to a larger part of the population, and this explains, at least in part, why practical science became

[11] See Ibn al-Akfānī, p. 59, and the translation of this passage in King 1996, pp. 303–304.

[12] al-Bīrūnī's remarkable treatise on the astrolabe (entitled *Istīʿāb al-wujūh al-mumkina fī ṣanʿat al-asṭurlāb*, "Comprehensive account of all possible ways of constructing the astrolabe") is often cited in the modern literature, although it has not been yet published. [Note added in proof: An edition by Muḥammad Akbar Jawādī al-Ḥusanī (Mashhad, 2001) has become available after completion of this study. See al-Bīrūnī, *Istīʿāb* in the bibliography.] It was composed in the author's youth, while he was in Gurganj. I shall frequently refer to this important work in the commentary; I have used MS Leiden Or. 591/4, pp. 47–175 (copied 614 H). For Ibn Sīnā's involvement with observational instruments see Wiedemann & Juynboll 1926.

[13] The foremost examples being al-Kūhī and Ibn al-Haytham; see p. 54, n. 19 and p. 183.

[14] The first century and a half of Mamluk rule (1250-1400) – which coincides with the temporal boundaries of the present study – is a period traditionally associated with the beginning of the so-called 'post-classical' age of Islam, a periodisation that now urgently ought to be abandoned. The Mamluks were former soldier-slaves of Turkic and Circassian origins who eventually rose to positions of power.

increasingly popular, as the number of treatises written specifically for beginners or for a non-specialised audience clearly attests.[15] During this period, instrumentation became localised within the frame of a new subdiscipline of astronomy, the science of astronomical timekeeping (*ʿilm al-mīqāt* or *ʿilm al-mawāqīt*). *Stricto sensu*, the science of *mīqāt* denotes the knowledge of determining the times of the sacred prayers. After 1250 AD the term acquired a broader meaning, and referred to the whole field of spherical astronomy, timekeeping, astronomical instrumentation, *qibla* computations, chronology and prediction of lunar crescent visibility.[16] It encompasses all aspects of *practical* astronomy, especially those of relevance to the Islamic community.[17] In the course of the thirteenth century this whole field became the domain of a new category of professionals, the *muwaqqit*s.[18] These astronomers, employed by a mosque or a madrasa, were primarily responsible for establishing the times of prayer, computing the *qibla* and constructing instruments such as sundials. A consequence of this professionalization of practical astronomy was a dramatic increase in texts dealing with *mīqāt*, along with a strengthened interest in instruments. But this phenomenon cannot be reduced to the realm of *muwaqqit*s, for a large number of scholars who were the leading specialists of the field are not known to have been employed officially in mosques. An independent scholar who already earned his living as a teacher might also have made substantial contributions as an expert of *mīqāt*, thus fulfilling the same function as a *muwaqqit*, albeit in an unofficial manner, by producing tables or instruments used by the mosque or madrasa where he was active. It is also well known that many muezzins were also *muwaqqit*s; in fact the two designations were frequently used interchangeably.

The basics of *mīqāt* were taught in mosques, madrasas and private houses, not necessarily as part of a fixed ‘curriculum’, but rather as an accepted and socially useful branch of knowledge. Muezzins or apprentice *muwaqqit*s were taught *mīqāt* along with numerous students whose inclinations may not have been mainly scientific. Although the standard topics of Muslim education (such as *uṣūl al-dīn*, *fiqh* and *kalām*) attracted large number of students and conferred prestige on their teachers, scientific disciplines like astronomy and mathematics, and the ‘rational sciences’ in general, were also continuously present in the educational scene and enjoyed considerable esteem, despite their apparently marginal status.[19] The *usefulness* of applied astronomy and mathematics for religious practice and for Islamic society in general (prayer times, *qibla*, lunar visibility, algebra of inheritance, practical geometry applied to religious ornamentation and architecture) certainly contributed to se-

[15] For a social history of religious education in Mamluk Cairo see Berkey 1992.
[16] See King 1983a.
[17] This is what David King has labelled “Astronomy in the service of Islam”: see King 1993a.
[18] see King 1996a.
[19] See Brentjes, “Respectability”.

cure that esteem to the eyes of the community. The same is true of other 'alliances' between secular sciences (such as logic and philosophy) and traditional ones.[20] Ibn al-Akfānī confirms the high social status of *mīqāt*, when he mentions that scholars have applied the five categories of Islamic law[21] to the science of astronomy, the higher category of *wājib* being reserved to the science of determining the prayer times,[22] whereas the last three categories of 'permissible', 'reprehensible' and 'forbidden' concern various levels of astrological doctrine.

The foundation of numerous mosques and madrasas through religious endowments (*waqf*) during the Mamluk period created a higher demand for specialists of *mīqāt*. Since not all institutions could afford to hire their own *muwaqqit* (in general, only major institutions had *muwaqqit*s among their personnel), their muezzins thus had to rely, for technical matters, upon the knowledge of others. This created a demand for the tools (computational methods, auxiliary tables, instruments and related treatises) and products (pre-compiled prayer tables and sundials) of *mīqāt* that are relevant to their activity. Such a climate was propitious for competition between specialists, who rivalled to attract students, and to provide them with the best teaching and the best instruments and methods.

A rare glimpse at the contents and context of this activity is provided by Ibn al-ʿAṭṭār, a fifteenth-century specialist on instruments who appears later in the following pages. He tells us that Ibn al-Majdī – a well-known astronomer of fifteenth-century Cairo[23] – taught him the elements of astronomy, and that he read under his supervision (*qaraʾa ʿalayhi*) about the construction of instruments, such as declining sundials (*munḥarifāt*[24]), and about theoretical astronomy (*hayʾa*), religious sciences (*ʿulūm al-dīn*) and jurisprudence (*fiqh*). We also learn that this teaching activity took place at the al-Azhar mosque, at Ibn al-Majdī's private residence, and at the madrasa of Jānibak,[25] and that Ibn al-ʿAṭṭār's association with his master lasted close to 20 years.[26]

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[20] Brentjes, "Respectability", pp. 14–17, 22. Cf. Michot 2000, p. 148, emphasizing the "interdisciplinarity" and interaction of "philosophy, theology (*kalām*), sciences and even Sufism".

[21] Namely, 1. *wājib* (necessary), 2. *mandūb* (recommended), 3. *mubāḥ* (permissible), 4. *makrūh* (reprehensible) and 5. *maḥẓūr* (forbidden, prohibited). The same five categories were already applied to astrology by Fakhr al-Dīn al-Rāzī; see Saliba 1982, p. 216 n. 14 (p. 56 of the reprint), quoting MS Escorial 909, f. 66v. It would be interesting to know whether Ibn al-Akfānī took this directly from al-Rāzī.

[22] Ibn al-Akfānī, p. 58.

[23] See Section 1.3.9.

[24] The text has منحفات.

[25] The text has جاى بك.

[26] This information occurs at the end of a late copy of Ibn al-ʿAṭṭār's treatise on quadrants composed in 830 H [= 1426/7] (see Section 1.3.9). The Arabic text is reproduced in King, *Fihris*, II, p. 368. Ibn al-ʿAṭṭār also says that he had previously studied under Nūr al-Dīn al-Naqqāsh ibn ʿAbd al-Qādir (on whom see King, *Survey*, no. C74), on whose notes his treatise is based.

Why did the practice of astronomy undergo such radical changes under the Mamluks? What conditions made possible the appearance of this new category of astronomers, the *muwaqqit*s? George Saliba has formulated the interesting thesis that the institution of the *muwaqqit* appeared as a reaction by the astronomers to the repeated attacks against astrology during the past centuries.[27] By associating themselves with religious institutions and unmistakably obviating themselves from practising astrology to earn their living, astronomers could successfully secure the religious and social legitimacy of their discipline. Saliba notes that a strong plea for the usefulness of astronomy and its distinctiveness from astrology had already been formulated in previous centuries, notably by al-Bīrūnī.[28] Although this animosity against astrology must have been one of the forces that led to a reshaping of astronomical practice during the twelfth to fourteenth centuries, it can hardly be accepted as the monocausal explanation of a complex phenomenon, which is deeply dependent upon a vast array of social and cultural changes experienced during the Ayyubid and Mamluk periods.[29] Be that as it may, a clearly observable trend is the relative, if not complete, exclusion of astronomers and astrologers from the court, and the remarkable marginality of the astrological literature produced during the fourteenth and fifteenth centuries.[30] In any event, astronomy became increasingly dominated by *mīqāt*, and its practitioners integrated themselves to a religious setting, thereby adopting the same conventions for transmitting their knowledge as those privileged by the religious scholars.

The shift of interest associated with the transformations in the practice of the mathematical sciences impelled new avenues of research, including theoretical ones.[31] Theoretical astronomy was not necessarily overshadowed by

[27] Saliba 1994, pp. 61, 65, 78–79.

[28] Saliba 1994, p. 60. This is most evident in al-Bīrūnī's treatises on mathematical geography (*Taḥdīd*, pp. 22–62 and translation pp. 1–33.) and on shadows (*Shadows*, I, pp. 1–9), both quoted by Saliba.

[29] Yet Saliba also offers a more nuanced statement in this respect, saying that the office of the *muwaqqit* "was created specifically as a result of the change in the conception of the role of the astronomer in the society" (Saliba 1994, p. 32).

[30] To be sure, astrology did not disappear! But the number of astrological works by Mamluk authors is comparatively few. Astrology and magic, of course, were not allowed in the context of the mosque, at least not officially, but it is well-known that works on such topics were read and copied within the confines of religious institutions. Moreover, there are few traces of astrology in a courtly context during the Mamluk period, much unlike medicine, which the ruling elite actively patronised (see Brentjes, "Respectability", p. 33). Reports of Mamluk astronomers practising astrology at the request of a patron are exceptional. So it is quite surprising to discover the existence of a horoscope prepared for a Mamluk *amīr* by the esteemed *muwaqqit* of al-Azhar and religious scholar Ibn al-Majdī (see King, *Survey*, no. C62 *sub* 5.5.1 – the horoscope is for one Naṣīr al-Dīn Abū 'l-Fatḥ Muḥammad, born in 802 H [= 1399/1400]). Such patronage activity was probably more frequent than we would assume, but it nevertheless appears to have been sporadic and unofficial.

[31] Among theoretical advances: mathematical geography (*qibla*), spherical trigonometry, the-

the dominating insistence on the practical. Ibn al-Shāṭir could indeed pursue his researches on the reform of Ptolemaic astronomy besides his functions as a *muwaqqit* and a teacher. Other developments may have been accidental consequences of the constant preoccupation with certain class of problems. The case of instrumentation is particularly illuminating in this respect: the practice and teaching of an astronomy dominated by *mīqāt* encouraged the explorations of fruitful paths in the design of instruments, which would have been more difficult to access in a different context.

Most of the historical issues presented in the above survey require detailed research which still needs to be conducted, a task beyond the scope of the present work. The above remarks of a preliminary nature nevertheless aimed at providing the reader with a clearer perspective of the place, role and virtues of practical astronomy, and especially of instrumentation, in the context of Egyptian and Syrian societies of the Mamluk period. Attention now turns to a work of major importance.

1.2 *An early Mamluk encyclopædia of* mīqāt *and instrumentation: al-Marrākushī's* Jāmiʿ al-mabādiʾ wa-l-ghāyāt fī ʿilm al-mīqāt

The astronomer Sharaf al-Dīn Abū ʿAlī al-Ḥasan ibn ʿAlī ibn ʿUmar al-Marrākushī[32] compiled in Cairo during the second half of the thirteenth century a remarkable *summa*[33] devoted to the science of *mīqāt*, which is the single most important source for the history of astronomical instrumentation in Islam.[34] Since it became the standard reference work for Mamluk Egyptian and Syrian, Rasulid Yemeni and Ottoman Turkish specialists of the subject,[35] it merits attention here.

al-Marrākushī, unfortunately, does not figure in any of the standard biographical dictionaries I have consulted, so the scanty evidence provided by his own work shall be used to shed some light on his person. He was obviously

ory of projections and sundial theory.

[32] On this individual see the article "al-Marrākushī", *EI*², VI, p. 598 (by D. A. King); on his writings see Suter, *MAA*, no. 363 and King, *Survey*, no. C17.

[33] To characterise this work, King has unfortunately often used the word 'compendium' by mistake (e.g. King 1983a, p. 539 or King, *Survey*, p. 59). In view of the nature and sheer size of al-Marrākushī's *Jāmiʿ*, its best Latin equivalent is without question *summa*.

[34] The first half (*Fann* 1 and the first three *qism*s of *fann* 2) was translated into French by J. J. Sédillot in 1822 and printed in two volumes in 1834-1835; the rest of the second *fann* was summarised in a very inadequate fashion (at least by modern standards) by his son L. A. Sédillot in an essay published in 1844. Both publications are respectively listed as Sédillot, *Traité* and Sédillot, *Mémoire* in the bibliography.

[35] The number of extant copies of this work proves its popularity: I am aware of 14 complete copies, 3 incomplete ones, and numerous fragments and extracts.

an emigré from the Maghrib active in Cairo.[36] It is not surprising, given the turmoil affecting al-Andalus and the Maghrib in the thirteenth century, that a scholar from the westernmost part of the Islamic world would decide to emigrate to Egypt, whose capital Cairo was indeed already established as the major cultural centre of the Arab-Islamic world. al-Marrākushī appears to have written his major work in Cairo during the years 675–680 H [= 1276–1282]. First, a solar table is given for the year 992 of the Coptic calendar (Diocletian era), corresponding to the years 674-75 H and 1275-76 AD. Also, some examples of chronological calculations are given for the year 680 H [= 1281/2], and his star table (in equatorial coordinates) is calculated for the end of the year 680 H. An interesting confirmation of his Maghribi origin and a testimony of his exile from there to Egypt is provided by his geographical table: 44 of the 135 localities featured in the list of latitudes are written in red ink to signify that the author visited these places personally and determined their geographical latitude *in situ* through observation. These 44 locations begin along the Atlantic coast of today's West Sahara, include numerous cities and villages in the Maghrib, two cities in al-Andalus (Seville and Cádiz), and continue along the Mediterranean coast via Algiers, Tunis and Tripoli to end up in Alexandria, Cairo, Minya and Tinnis.[37] al-Marrākushī's Western Islamic heritage is also apparent in the fact that his chapters on precession and solar theory depend upon the works of Ibn al-Zarqālluh and Ibn al-Kammād. al-Marrākushī died, certainly in Cairo, between the years 680 H and *ca*. 725 H.[38]

The voluminous[39] *Jāmiʿ al-mabādiʾ wa-l-ghāyāt* has repeatedly been qualified to be a mere compilation of older sources without original content.[40] It is true that the book depends heavily upon the works of predecessors; this is, after all, what we should expect of a comprehensive synthetic work, a *summa*. Yet in its organization, style and purpose, it is definitively original and without precedent. In fact, no single part of the work can be proven to reproduce the words of an earlier author, except for the few sections where al-Marrākushī

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[36] Since the work of the Sédillots father and son in the first half of the nineteenth century and until the 1970s, al-Marrākushī was thought to have been active in the Maghrib.

[37] See al-Marrākushī, *Jāmiʿ*, I, pp. 84–87; Sédillot, *Traité*, pp. 199–204; cf. Lelewel 1850-57, I, pp. 134–142 and atlas pl. XXII; Sezgin, *GAS* X, pp. 168–172.

[38] He was certainly alive in 680 H since many examples in his work are given for that year. And in two early fourteenth-century sources, namely, the anonymous *Kanz al-yawāqīt* datable to 723 H (MS Leiden Or. 468, f. 91r; the date is related to a star table ascribed to al-Marrākushī on f. 69v) and in Najm al-Dīn's treatise (see pp. 230 below), he is mentioned as a deceased scholar. A copy of his *Jāmiʿ* was made in the year 695 H (MS Istanbul Nuruosmaniye 2902, see Krause 1936, p. 493), which I have not consulted, but which could provide an earlier *terminus ante quem* in case the author's name in it is followed by the eulogy *raḥmat Allāh ʿalayhi*.

[39] Most complete copies cover 250 to 350 folios.

[40] "Most of the material was apparently culled from earlier sources which are not identified by the author and which have not yet been established." Article "al-Marrāku<u>sh</u>ī" in *EI*[2] (by D. A. King).

clearly states from whom he is quoting.[41] In those occasional cases where an earlier source is mentioned, al-Marrākushī's text always turns out to be either a major rewriting of the original or an independent paraphrase. In fact, al-Marrākushī himself tells us in the introduction how he compiled his *summa* and confirms our understanding about the nature and purpose of the work:

لمّا رأيت ذلك حملتني النصيحة على تصنيف هذا الكتاب وضمّنته جميع ما يراد من المطلوب وأصلحت فيه من أعمالهم الفاسدة ما أمكن إصلاحه واختصرت فيه من الأعمال الطويلة وتممت فيه الأعمال الناقصة وأضفت إلى ذلك ما استنبطته من المطالب النافعة جميع ذلك كلّه عن براهين صحيحة

> Considering this, some friendly advice induced me to compose this book, in which I included everything that can be desired on this topic. I have rectified in it their[42] incorrect operations which could be corrected, I have abbreviated the overly lengthy ones and I have completed those which are lacunary, and I have added to this the useful propositions of my own invention, all of this based on exact proofs.

The *Jāmiʿ al-mabādiʾ wa-l-ghāyāt* is written in a relatively literate style, quite different from the dry prose that is the norm for Mamluk writings on technical topics. The author displays a good encyclopædic knowledge, especially in the subject matters he is writing about and also occasionally on philosophical issues.[43] His indebtedness to his predecessors and his profound knowledge of their works is everywhere apparent. The book is also very logically organised and is replete with cross references.[44] New information is often introduced just before it is effectively used: thus the table of geographical latitudes immediately precedes the first chapter in which knowledge of the latitude is required, and the same is also true of the tables of terrestrial longitude and declination of stars. In its structure and intent, al-Marrākushī's work is thus in many ways comparable to the project achieved for medicine by Ibn Sīnā with his *Qānūn*, or for mathematics by the eleventh-century Andalusī mathematician Ibn Hūd with his *Istikmāl*, two works characterised by

[41] Chapter 7 of Fann 3 on the use of the sphere (in 90 divisions) has been said to reproduce verbatim the contents of an earlier anonymous treatise entitled *Mukhtaṣar fī kayfiyyat al-ʿamal bi-l-kura*, extant in MS Istanbul Aya Sofya 2673/2 (in 88 divisions); see King 1979b, p. 454 and idem, *Survey*, p. 59; it is listed in Krause 1936, pp. 525–526. But the converse is true: the treatise in the latter manuscript, as its title suggests, represents a slight abridgment (*mukhtaṣar* – two of the 90 chapters having been omitted) of al-Marrākushī's original text. Indeed, the introductory text to al-Marrākushī's Chapter 7 makes it evident that we are reading his very own words, and that he had compiled his 90 chapters from various sources he had access to. Furthermore, since the Istanbul manuscript was copied in 864 H, almost 200 years after the composition of the *Jāmiʿ*, it is of no avail to any attempt to determine sources which al-Marrākushī might have used.

[42] He is probably referring to his predecessors in general.

[43] See for example the passage translated on p. 80 below.

[44] In the introduction it is stated that cross-references have been used in order to avoid repetitions.

their comprehensiveness and brilliance, and by their logical and didactical organisation.[45]

The arrival of al-Marrākushī in Cairo must have coincided with the establishment of the first offices of *muwaqqit*s in Mamluk mosques. His work was thus certainly a reaction to a demand from Egyptian society (more specifically the mosque administration, the muezzins and *muwaqqit*s, instrument-makers and interested students). His motive for writing his work is the inadequate education of instrument-makers and their methodological failures. It is surprising not to find any reference to the profession of the *muwaqqit* or to the milieu of the mosque; this appears to indicate that al-Marrākushī was an independent scholar without institutional affiliation. His introduction suggests that his readership consisted of instrument-makers, that is, artisans and practitioners of applied science who are not professional astronomers. To this group could belong most muezzins of Cairo, but hardly any *muwaqqit* with a serious education. This affirmation is contradicted by the technical level of the book, which certainly assumes the reader to know at least the basics of arithmetic, geometry, spherics, algebra and trigonometry. The *Jāmiʿ al-mabādiʾ wa-l-ghāyāt* is in fact a comprehensive reference work of intermediate to advanced level, not an introductory work on the topic of astronomical timekeeping.[46] Its ideal readership, thus, would be made of active and apprentice *muwaqqit*s, and of the group of all specialists of *mīqāt* and instrumentation who gravitated around them.

The *Jāmiʿ* is made up of four books (*fann*) on the following topics:

1. On calculations, in 67 chapters (*faṣl*). This books gives exhaustive computing methods (without proofs) concerning the topics of chronology, trigonometry, geography, spherical astronomy, prayer times, the solar motion, the fixed stars and gnomonics.
2. On the construction of instruments, in 7 parts (*qism*). The first part concerns graphical methods in spherical astronomy and gnomonics. The second to seventh parts then treat the construction of 2) portable dials, 3) fixed sundials, 4) trigonometric and horary quadrants, 5) spherical instruments, 6) instruments based on projection and 7) observational and planetary instruments.
3. On the use of selected instruments, in 14 chapters (*bāb*).
4. The work ends with a 'quiz' – a series of questions and answers – in 4 chapters (*bāb*), whose aim is to train the mental abilities of the students. The first chapter has 21 questions and answers (Q&A) requiring

[45] "The *Istikmāl* is essentially an intelligent and efficient abridgement of other sources, with few original contributions", Hogendijk 1986, p. 48. See further Hogendijk 1991.

[46] A few decades after al-Marrākushī's composition of the *Jāmiʿ*, the scholar Ibn al-Akfānī mentioned it as the standard comprehensive work on the topic of timekeeping. He also mentions the *Nafāʾis al-yawāqīt* (anonymous and not extant) as being a short book on the subject; see Ibn al-Akfānī, p. 59.

no calculation, the second one has 40 Q&A requiring mental calculation (*ḥisāb maftūḥ*), the third one has 18 Q&A requiring geometrical methods, and the last one has 22 Q&A requiring algebraic methods.

1.3 *Some fourteenth-century Mamluk authors on instrumentation*

1.3.1 *al-Maqsī*

Shihāb al-Dīn Abū ’l-ʿAbbās Aḥmad ibn ʿUmar ibn Ismāʿīl al-Ṣūfī al-Maqṣī was a contemporary of al-Marrākushī. He is known for his timekeeping tables for the latitude of Cairo and for a work on fixed sundials for the latitude of Cairo, with tables, composed in 675 H [= 1276/7].[47] He is not known to have otherwise contributed to instrumentation.

1.3.2 *Ibn Samʿūn*

Naṣīr al-Dīn Muḥammad ibn Samʿūn (d. 737 H [= 1336/7]) was *muwaqqit* at the Mosque of ʿAmr in Fusṭāṭ.[48] He might well be the author of the anonymous *Kanz al-yawāqīt* (composed around 723 H), which contains a reference to various members of a family Ibn Samʿūn who were *muwaqqit*s in Cairo in the thirteenth century.[49] Ibn Samʿūn wrote original treatises on various kinds of instruments.[50]

1.3.3 *al-Mizzī*

Zayn al-Dīn (or Shams al-Dīn) Abū ʿAbd Allāh Muḥammad ibn Aḥmad ibn ʿAbd al-Raḥīm al-Mizzī al-Ḥanafī was born in 690 H [= 1291], probably in al-Mizza near Damascus, and studied in Cairo under Ibn al-Akfānī. He was first appointed *muwaqqit* in al-Rabwa, a quiet locality near Damascus, and later at the Umayyad Mosque in Damascus, a position he held until his death early in 750 H [= 1349].[51] al-Mizzī is the author of treatises on the use of the astro-

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[47] Suter, *MAA*, no. 383; Brockelmann, *GAL*, I, p. 626 and Suppl. I, p. 869; King, *Survey*, no. C15. On his tables for timekeeping, see King, *SATMI*, I, §§ 2.1.1, 4.1.3, 5.4.4. On his work on sundials, see the article “Mizwala” in *EI*^{2}, VII, pp. 210–211 (by D. King).

[48] Suter, *MAA*, no. 398; Brockelmann, *GAL*, II, p. 155; King, *Survey*, no. C24.

[49] Preserved in the unique manuscript Leiden Or. 468.

[50] On those of the unusual kinds, see p. 90, n. 127 and p. 222.

[51] On his biography, see al-Ṣafadī, *Nakt*, p. 209; Ibn Ḥajar, *Durar*, III, p. 410 (no. 3392); see also Mayer 1956, p. 61. On his works, see Suter, *MAA*, no. 406; Brockelmann, *GAL*, II, pp. 155–156 and Suppl. II, pp. 156, 1018; King, *Survey*, no. C34.

labe, the astrolabic quadrant and the sine quadrant;[52] he also wrote on the use of less common instruments, such as the *musattar* and the *mujannaḥ* quadrants.[53] Although he made few original contributions to instrument-making, al-Mizzī was nevertheless an important and influential authority in the field, whose didactical treatises were appreciated by students of *mīqāt*. The instruments he made were highly praised as being the best of his times, and sold for considerable prices, namely 200 *dirham*s or more for an astrolabe, and at least 50 *dirham*s for a quadrant.[54] Some five quadrants made by him are extant, dated between 727 and 734 H [= 1326/7–1333/4].[55] According to Ibn al-ʿAṭṭār he also made astrolabes with mixed projections.[56] al-Mizzī also excelled in oiling bows (*baraʿa fī dahn al-qisī*) and impressed his contemporaries by constructing mechanical devices such as those of the Banū Mūsā.

1.3.4 *Ibn al-Sarrāj*

Shihāb al-Dīn Abū ’l-ʿAbbās Aḥmad ibn Abī Bakr ibn ʿAlī ibn al-Sarrāj al-Qalānisī al-Ḥalabī[57] was the most important specialist of instrumentation in the Mamluk period.[58] His *laqab* al-Qalānisī[59] may indicate that he or his family was involved with the profession of making skull-caps (*qalānis*), but another possible interpretation would be that he had studied at the Dār al-Ḥadīth (also called a *khānqa*) al-Qalānisiyya in Damascus, which was founded by the celebrated historian Abū Yaʿlā Ḥamza Ibn al-Qalānisī (d. 555 H [= 1160]).[60] Ibn al-Sarrāj’s dates of birth and death are not known.[61] Ibn al-Ghuzūlī (see

[52] In particular his treatises *al-Rawḍāt al-muzhirāt fī ’l-ʿamal bi-rubʿ al-muqanṭarāt* (on the astrolabic quadrant) and *Kashf al-rayb fī ’l-ʿamal bi-l-jayb* (on the sine quadrant) were quite popular.

[53] On the *musattar*, see Section 2.4.2; on the *mujannaḥ*, see Charette 1999a.

[54] This is reported by al-Mizzī’s contemporary al-Ṣafadī (*Nakt*, p. 209). The fifteenth-century scholar Ibn Ḥajar, whose biographical notice seems to be based on that of al-Ṣafadī, gave those prices as 10 *dīnār*s for astrolabes and 2 *dīnār*s for quadrants; these are probably converted from the above figures (with 20 *dirham*s to the *dīnār*). Cf. Mayer 1956, p. 61.

[55] Three of them are described in Dorn 1865, pp. 16–26 and plates; Féhérvari 1973; King 1993b, p. 438. Cf. Combe 1930, p. 56, and Mayer 1956, pp. 61–62.

[56] See p. 73, n. 83.

[57] The *nisba* al-Ḥamawī is given in MS Manchester Rylands 361, f. 36r, and in the introduction of a treatise by Ibn al-Ghuzūlī (see *ibid.* f. 38v, and King, *Fihris*, II, p. 566); this may indicate that he or his family hailed from Ḥamā in Syria.

[58] On his works, see Brockelmann, *GAL*, II, p. 155 and Suppl. II, p. 156; and King, *Survey*, no. C26.

[59] Attested in MSS Princeton, Yahuda 296, f. 1r, Paris 2459, f. 98r-v; Damascus, Ẓāhiriyya 4133, f. 1v.

[60] See Sauvaire 1893–1896, I, pp. 29–30 [= *Journal Asiatique* 1894, pp. 279–280]. The text of al-ʿAlmāwī (d. 1573 AD) translated by Sauvaire gives the dates of his birth and death erroneously as 649 H [= 1251/2] and 6 Dhū ’l-Ḥijja 729 H [= 30 September 1329]!

[61] The information in the modern literature about his year of death is confused and based on a misunderstanding. Ahlwardt (*Verzeichnis*, no. 5799/1, p. 234) writes “um 726/1326 am Leben”, and this information was repeated by Suter (*MAA*, p. 200) and Schmalzl (1929, p. 108). But

below) says in his treatise on an instrument of Ibn al-Sarrāj's invention that the latter lived and died in Aleppo.[62] There is some indication that he also spent part of his life in Cairo.[63] He was already active in 714 H [= 1319/20], in which year he copied MS Istanbul Aya Sofya 1719, containing Muḥyī al-Dīn al-Maghribī's recension of Euclid's *Elements*.[64] There is yet more evidence that his mathematical education was exceptional: he owned a precious manuscript (Aya Sofya 2762) copied in 415 H [= 1024/5] by none other than Ibn al-Haytham, and containing the *Conics* of Apollonius in the translation of Thābit ibn Qurra, with improvements by the Banū Mūsā.[65] He also wrote a marginal note in a copy of al-Karajī's important treatise on algebra *al-Fakhrī*, stating that part of the work was taken from Diophantus.[66] He made a universal astrolabe in 729 H [= 1328/9] (see below) and was still active in 748 H [= 1347/8], just before the great plague of 749 H [= 1348/9], since in that year he wrote a treatise on geometrical problems, of which the autograph is extant.[67]

Ibn al-Sarrāj's contribution to the field of instrumentation was first rate. Ibn al-ʿAṭṭār (see further below) ascribes him the invention of the following instruments: the *musattar* ("folded") and *mujannaḥ* ("winged") quadrants, the semicircle called *al-jayb al-ghāʾib* ("the hidden trigonometric grid"), and an unusual sine quadrant called *jayb al-awtār*, which is equivalent to Ibn al-Shāṭir's *ʿAlāʾī* quadrant (see below). Except for the latter, he indeed wrote

Brockelmann (*GAL*, II, p. 155) wrote instead "starb um 726/1326 in Aleppo", and Mayer (1956, p. 34), realizing that Ibn al-Sarrāj had made an astrolabe in 729 H, modified this into "died in or after 729/1329"; Curiously, ʿAzzāwī 1958 has "*Ibn al-Sarrāj al-Yamanī (!) al-mutawaffā sanati 726 h / 1335 m*", without indicating any source (he does not appear to have used Brockelmann).

62 Ahlwardt (*Verzeichnis*, no. 5847) and others have claimed that Ibn al-Ghuzūlī's treatise was composed in 745 H [= 1344/5]; in fact, the author states in his introduction the following: "In the month of Muḥarram 745 some friend of mine and his companions presented to me . . . an instrument invented by Ibn al-Sarrāj – may God Almighty have mercy upon him – who lived and died in Aleppo. They asked me to explain how to use the instrument invented by the aforementioned and which he called *al-jayb al-ghāʾib*." (MS Cairo ZK 782/7, ff. 35r–40v: introduction reproduced in King, *Fihris*, II, p. 566; and MS Manchester Rylands 361, ff. 38r–40v, on f. 38v). The above, clearly, does not necessarily mean that the treatise was written in 745 H. In fact Ibn al-Sarrāj was alive in 748 H (see below), which gives us a *terminus post quem* for the composition of Ibn al-Ghuzūlī's treatise.

63 According to Ibn Abi 'l-Fatḥ al-Ṣūfī (MS Berlin Wetzstein 1139, ff. 37v–47r, on f. 37v), Ibn al-Sarrāj sent a treatise on an instrument of his invention to Ibn al-Shāṭir in Damascus, who completed it with new markings. The latter then wrote wrote a treatise explaining them, which he sent to Cairo. This seems indeed to imply that Ibn al-Sarrāj was then active in Cairo. See Ahlwardt, *Verzeichnis*, no. 5844, Schmalzl 1929, p. 111, and Charette 1999a.

64 See Krause 1936, p. 506 (no. 11).

65 On this manuscript, see Krause 1936, p. 449; other owners of the book were Zayd ibn al-Ḥasan al-Kindī, Muḥammad ibn Abī al-Jarrāda (Suter, *MAA*, no. 385), and Aḥmad al-Kawm al-Rīshī (809 H [= 1406/7]) (Suter, *MAA*, no. 428; King, *Survey*, no. C41). This version of the *Conics* is edited in Toomer 1990.

66 MS Paris 2459, f. 98r (information kindly communicated by Prof. David King).

67 See King, *Fihris*, II, pp. 897–898; a photograph of the colophon with his signature is illustrated in King, *Survey*, plate CIIIc.

treatises on all of these ingenious instruments and some others, characterised by their concise and efficacious language. These instruments include various universal trigonometric grids[68] and a special form of astrolabic quadrant.[69] His treatise on spherical astronomy and instruments (preserved in MS Princeton Yahuda 296) deserves investigation, as well as the commentary on it by Ibn al-Majdī.[70] He also 'reinvented' (or, more precisely, 'adapted') the universal astrolabe of ʿAlī ibn Khalaf (see Section 2.6.4). The universal astrolabe he made in 729 H integrates to the basic universal astrolabe of the latter a series of elements and ideas that make it "the most sophisticated astronomical instrument from the entire medieval and Renaissance periods".[71]

1.3.5 *Ibn al-Shāṭir*

ʿAlāʾ al-Dīn Abū al-Ḥasan ʿAlī ibn Ibrāhīm ibn Muḥammad ibn al-Himām Abī Muḥammad ibn Ibrāhīm al-Anṣārī al-Muṭaʿʿim al-Dimashqī, known as Ibn al-Shāṭir, was the leading astronomer of Mamluk Egypt and Syria. His life is well documented.[72] He was born on 15 Shaʿbān 705 H [= 1 March 1306] in Damascus;[73] having lost his father at an early age, he was tutored by his grandfather and then sent to the husband of his maternal aunt and to the son of his father's paternal uncle, from whom he learned the technique of inlaying ivory (*taṭʿīm al-ʿāj*, hence his *laqab* "*al-muṭaʿʿim*"). He also learned some mathematics and astronomy in his native city and then went to Cairo and Alexandria to further his studies in these fields. He occupied the position of *muwaqqit* of the Umayyad Mosque in Damascus at least from 733 H [= 1332/3] until his death in 777 H [= 1375/6]; he was also chief muezzin of the mosque. Although he is best known for his important contributions to observational and planetary astronomy, his professional activities also dealt with instrumentation. He made several instruments himself (three astrolabes, one

68 On the semicircle and the "winged" quadrant, see Schmalzl 1933, pp. 108–112, and Charette 1999a.

69 See Section 2.4.2.

70 See already Charette 1999a.

71 King 1986, p. 7. A monograph by D. A. King and the present author on the Mamluk tradition of universal astrolabes in general and on the Benaki instrument in particular is being prepared for publication (listed in the bibliography as King & Charette, *Universal Astrolabe*). For an epigraphic description see Combe 1930, pp. 54–56.

72 Most biographical sources concerning his life (including two previously unpublished ones) are reproduced in Kennedy & Ghanem 1976, pp. 11–15 (Arabic section) and summarised on pp. 21–22. See also Wiedemann 1928; Reich & Wiet 1939-40; Sauvaire 1894–1896, 277–278 [= *Journal Asiatique*, 1896, pp. 207–208: Sauvaire's translation of al-ʿAlmāwī (who quotes the well-known passage of al-Ṣafadī) is imperfect]; Mayer 1956, p. 40; and *DSB*, s.v. (article by D. A. King).

73 Most biographers give 13 Rabīʿ I 704 [= 13 October 1304] instead, but al-Ṣafadī (Kennedy & Ghanem 1976, p. 12 of the Arabic section) says that he had this information from Ibn al-Shāṭir himself.

'compendium box' and one sundial are extant[74]) and invented a large number of original instruments (mainly trigonometric grids, a universal astrolabe and a universal compendium). He composed numerous didactical treatises on various instruments, notably those he invented.[75]

1.3.6 *Ibn al-Ghuzūlī*

The fourteenth-century instrument specialist Shams al-Dīn Abū ʿAbd Allāh Muḥammad ibn Muḥammad Ibn al-Ghuzūlī made a quadrant for the chief muezzin of the Umayyad Mosque in Damascus in 735 H,[76] and one can assume that his entire career unfolded in that city.[77] He was still active in 779 H, in which year he composed a work on Ibn al-Shāṭir's square trigonometric grid (*al-murabbaʿa*).[78] Ibn al-Ghuzūlī devised the crescent (*hilālī*) quadrant, a special form of the astrolabic quadrant on which the ecliptic is shaped as a crescent, and also the *thumn al-dāʾira*, that is, the "eighth of a circle" (or "octant"), which consists of two distinct set of markings on both sides of an octant: one side bears astrolabic markings – obtained by folding those of an astrolabic quadrant about the 45°-radius – and the other side bears a special

[74] The three astrolabes are: a standard astrolabe dated 726 H (Paris, Observatoire) and two universal ones dated 733 H (Cairo, Museum of Islamic Art, and Paris, Bibliothèque Nationale). The 'compendium box' is preserved in the Awqāf library in Aleppo. The horizontal sundial, dated 773 H [= 1371/2], is preserved in the Archaeological Museum, Damascus. See the next note for references to the literature on these instruments.

[75] The instruments of his invention are the following:

- A triangular trigonometric grid called *al-rubʿ al-tāmm* or *al-muthallath*, invented between 733 and 739 H [= 1332/2 and 1338/9] (see Schmalzl 1929, pp. 105–108).
- A variant of the above, called *al-rubʿ al-ʿAlāʾī*, *rubʿ al-awtār* or *jayb al-awtār* (see Schmalzl 1929, pp. 100–105).
- A universal astrolabe with rotating grid of horizons, combined with a trigonometric grid on the back, called *al-āla al-jāmiʿa*, (unstudied, but see King 1988, pp. 164–165).
- A square trigonometric grid (a variant of the sine quadrant) called *al-murabbaʿa* (unstudied).
- A composite instrument (compendium) called *ṣandūq al-yawāqīt* (see Janin & King 1977).

[76] On his quadrant, see Morley 1860; Schmalzl 1929, pp. 37–38; Mayer 1956, pp. 66–67. On his works, see Suter, *MAA*, no. 412; Brockelmann, *GAL*, II, pp. 331–332 and Suppl. II, p. 364; King, *Survey*, no. C33.

[77] The information in King 1983a, p. 553 and idem 1988, p. 169, that he was active in Cairo appears to be inexact. Furthermore, Schmalzl (1929, pp. 112–113) claims that he was a "Schüler oder Vertrauten des nicht unbedeutenden arabischen Gelehrten Schems al Din Muḥ. Jahen Juzei (?)"; but I was unable to find this information where Schmalzl supposedly did, namely, at the end of the introduction of MS Berlin Ahlwardt no. 5838 [= codex Pm 228, ff. 58v–60v, copied 849 H], so this probably results from a confusion with another author or a different manuscript.

[78] MS Manchester Rylands 361, ff. 64r–65v.

form of trigonometric grid.[79] Ibn al-Ghuzūlī also wrote on the sine quadrant, on Ibn al-Sarrāj's 'concealed grid' (*al-jayb al-ghāʾib*) and on the *musātira*.[80]

1.3.7 *al-Bakhāniqī*

Shams al-Dīn Aḥmad ibn Muḥammad ibn Aḥmad al-Azharī al-Bakhāniqī worked in the Yemen and dedicated one of his works to an officer of the Rasūlid Sultan Mujāhid (reg. 721–764 H [= 1322–1363]);[81] he was later active in Cairo.[82] He was responsible for editing the "main Cairo corpus of tables for timekeeping".[83] In the field of instrumentation he is known for his extension of al-Farghānī's tables for constructing astrolabes[84] and for various treatises on the use of the astrolabic, sine, *musattar* and *shakkāzī* quadrants.[85] He was still active in 774 H [= 1374/5], in which year he acquired MS Istanbul Topkapı Ahmet III 3343, a valuable book in two volumes containing the complete text of al-Marrākushī's *Jāmiʿ*.[86]

1.3.8 *Ṭaybughā al-Baklamishī and his son ʿAlī*

ʿAlāʾ al-Dīn Ṭaybughā al-Dawādār al-Baklamishī[87] lived in Egypt in the late fourteenth century.[88] The title of *dawādār* (*stricto sensu* the *amīr* in charge of the royal inkwell) signals us that Ṭaybughā was an important officer of the

[79] This instrument, especially its trigonometric grid, still needs proper investigation. Schmalzl's description of the grid (Schmalzl 1929, pp. 112–114) is inaccurate, since it is based on the text of MS Berlin Pm 228, ff. 58v–60v, which is corrupt.

[80] See King, *Survey*, no. C33 and Ahlwardt, *Verzeichnis*, nos. 5837 and 5838.

[81] MS Dublin CB 4090, f. 1v. In this manuscript the *laqab* "*al-mīqātī*" is also given. According to MS Manchester Rylands 361, f. 56r, al-Bakhāniqī was also known as Ibn Muʿīnī al-Khaṭīb.

[82] On his works, see King, *Survey*, no. C28 and King 1983c, no. 13.

[83] King 1983a, p. 540. For a thorough analysis of this corpus and its history see now King, *SATMI*, I, § 2.1.1 and II, § 5.6.

[84] Preserved in MS Dublin CB 4090, 53 ff.

[85] His treatise on the *shakkāzī* quadrant was composed in 760 H [= 1358/9]: see MS Manchester Rylands 361, ff. 56r–57v.

[86] His mark of ownership can be read on the title-page of al-Marrākushī, *Jāmiʿ*, I, p. 1.

[87] The orthography Baklamīshī is also attested: see King, *Fihris*, I, *sub* DM 774, and Ḥājjī Khalīfa, *Kashf al-Ẓunūn*, I, col. 866–867.

[88] On his works, see Brockelmann, *GAL*, II, pp. 168–169 and Suppl. II, p. 167; King, *Survey*, no. C53. In his treatise on the use of the *shakkāzī* quadrant (I have used MS Princeton Yahuda 373, ff. 149v–157v) he uses an obliquity of 23;31°, which has been observed by Ibn al-Shāṭir in Damascus in the year 750 H [= 1349/50] (this information is recorded in Ibn al-Shāṭir's *Zīj*: see MS Oxford Bodleian Selden A inf. 30, ff. 140v–142r). Ṭaybughā also gives an example (f. 157r of the Princeton MS) of the heliacal rising of Sirius when the sun is in 5° Leo, for Cairo, in the year 1115, without specifying the era, which can only be the Coptic calendar: the above solar longitude would imply the date *ca*. 20 July 1399. (These remarks should be considered provisory, since they are only based on the above-mentioned copy; the information should be checked against the older copy Cairo DM 774, copied 864 H [= 1459/60]).

Mamluk sultanate.[89] He may thus well have been the only contributor to our subject who had a position of high social standing outside of the religious institutions. In the secondary literature, it is often stated that Ṭaybughā was the inventor of the *shakkāzī* quadrant, but we shall see in Section 2.6.7 that this cannot be the case. We can identify him with near certainty with Ṭaybughā al-Ashrafī al-Baklamishī al-Yūnānī, author of a well-known treatise on archery composed during the reign of sultan al-Malik al-Ashraf Shaʿbān (reg. 1362–1377).[90] Although Ṭaybughā is clearly a Turkic name, his *nisba* al-Yūnānī suggests a connection with Greece, whilst *al-Ashrafī* must be related to his association with the above-named sultan. His son ʿAlāʾ al-Dīn Abū ʾl-Ḥasan ʿAlī was *muwaqqit* at the Umayyad Mosque in Aleppo *ca*. 1400. He wrote on the sine, astrolabic and *shakkāzī* quadrants.[91]

1.3.9 *Important authors from the fifteenth century*

- Jamāl al-Dīn al-Māridīnī was a student of Ibn al-Shāṭir.[92] He wrote on the double *shakkāzī* quadrant (see Section 2.6.7).

- Shihāb al-Dīn Abū ʾl-ʿAbbās Aḥmad ibn Rajab ibn Ṭaybughā al-Majdī al-Shāfiʿī, a student of Jamāl al-Dīn al-Māridīnī, was a *muwaqqit* at the al-Azhar Mosque and head of the teachers at the Jānibakiyya madrasa.[93] He was one of the major astronomers of fifteenth-century Cairo and wrote numerous influential treatises, notably on instrumentation. He was born in Cairo in Dhū ʾl-Ḥijja 767 H [= August 1366] and died on the night of Saturday 11 Dhū ʾl-Qaʿda 850 H [= 27/28 January 1447].

- Ibn al-ʿAṭṭār was a student of Ibn al-Majdī and Nūr al-Dīn al-Naqqāsh.[94] In 830 H [= 1426/7] he wrote an important comprehensive

[89] See "Dawādār" in *EI*², II, p. 172 (by D. Ayalon), where it is stated that this office became important only under the Circassian Mamluks (who seized power in 1382). More precise biographical data – which I have not yet systematically sought – would be necessary in order to assess Ṭaybughā's ranking within the Mamluk administration.

[90] Published in English translation by Latham 1970. See also the article "Ḳaws" in *EI*², IV, p. 797. The Arabic text has been published in 1999: see al-Baklamīshī, *Ghunyat al-rāmī*. Note that in the article "Ḥisāb al-ʿaqd" in *EI*², III, pp. 466–467 (by C. Pellat), a work on dactylonomy is wrongly ascribed to him; for clarifications see Ruska 1920, pp. 91, 95, 108.

[91] See King, *Survey*, no. C54; King 1988, pp. 169–170. His treatise on the *shakkāzī* quadrant is investigated in Samsó & Catalá 1971 and Samsó 1971 (where he is confused with Ibn al-Majdī).

[92] Suter, *MAA*, no. 421; Brockelmann, *GAL*, II, p. 218; King, *Survey*, no. C47.

[93] On his life, see al-Sakhāwī, *Ḍawʾ*, I, pp. 300–302. Ibn Taghrībirdī, *Manhal*, I, p. 279 (no. 255); al-Ṣuyūṭī, *Naẓm*, p. 42. On his works, see Suter, *MAA*, no. 432 (and "Nachträge", p. 178); Brockelmann, *GAL*, II, pp. 158–159 and Suppl. II, pp. 158–159; King, *Survey*, no. C62.

[94] On his life, see al-Sakhāwī, *Ḍawʾ*, IX, p. 3 (no. 13). On his works, see Suter, *MAA*, no. 431; Brockelmann, *GAL*, II, pp. 157–158 and Suppl. II, p. 158; ʿAzzāwī 1958, pp. 202–203; King, *Survey*, no. C66. On al-Naqqāsh, see King, *Survey*, no. C74.

treatise on the construction of all the instruments (especially the quadrants) that were invented in the fourteenth century, and which contains interesting historical information.[95]

- ʿIzz al-Dīn ibn Muḥammad al-Wafāʾī was *muwaqqit* at the Mosque of al-Muʾayyad in Cairo.[96] He died in 876 H [= 1471/2]. He invented a type of equatorial sundial and wrote an important treatise on the universal astrolabe made by Ibn al-Sarrāj, which had come into his possession.

- Badr al-Dīn Abū ʿAbd Allāh Muḥammad ibn Muḥammad ibn Aḥmad, Sibṭ al-Māridīnī (826–934 H [= 1422/3–1527/8]), grandson of Jamāl al-Dīn, studied under Ibn al-Majdī and was *muwaqqit* of al-Azhar in Cairo. His was an important author of didactical treatises, notably on instruments.[97]

1.4 *Themes and incentives of Mamluk* mīqāt *literature*

Inevitably, the emphasis on the practical and useful aspects of astronomy brought about a change in the practice and transmission of science. Mamluk authors on *mīqāt* had new sensibilities and different aims than their predecessors. Their writings reflect both their own priorities and preoccupations and the requirements of the religious institutions that employed them as well as the expectations of their audience. I now discuss selected themes in Mamluk astronomy to demonstrate its peculiar flavour, especially with regard to the *mīqāt* tradition, and to illustrate the nature and scope of science in late medieval Islamic society.

1.4.1 *The interaction of folk and mathematical astronomies*

Until a few decades ago the picture of scientific activity in Islam was limited to an appreciation of the reception, transformation and transmission of the sciences of the Ancients. No historian of science could possibly imagine that other scientific traditions coexisted with them, and that non-mathematical, pre-Islamic scientific lore continued to flourish for centuries, especially so-called 'folk astronomy'.[98] In fact, not only did these traditions develop in parallel, they also occasionally interacted. We shall present below a work by

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[95] This is entitled *Kashf al-qināʿ fī rasm al-arbāʿ*.

[96] Suter, *MAA*, no. 437; Brockelmann, *GAL*, II, pp. 159–160 and Suppl. II, pp. 160; King, *Survey*, no. C61.

[97] Suter, *MAA*, no. 445 (and "Nachträge"); Brockelmann, *GAL*, II, pp. 216, 468 and Suppl. II, pp. 215–217, 468; King, *Survey*, no. C97.

[98] These traditions are now well documented: see the surveys of Islamic folk astronomy in Varisco 2000 and King 1993d.

Najm al-Dīn (Section 1.5) pertaining to a hybrid form of folk and mathematical astronomy. Also, the contents of Ch. 91 of his instrument treatise edited in the present study can likewise be characterised as a hybrid product of both traditions.

1.4.2 *Exact* versus *approximate methods*

Problems solved with the methods of folk astronomy are, from perspective of mathematically-trained scholars, necessarily inaccurate, if not inexact. This is why twentieth-century historians of the mathematical sciences have often labelled their field of investigation the "history of exact sciences". Yet, any modern physicist is well aware that, in practice, exactness is an illusion. It is most often only through approximations that a difficult problem can be solved. Medieval astronomers too, especially those concerned with practical applications, frequently approached difficult problems with a similar attitude. Why should one suffer through a long and painful exact procedure when a straightforward approximation would yield a satisfying result within the desired range of accuracy? In the domain of timekeeping such a position is particularly relevant.

The introduction of al-Marrākushī's *Jāmiʿ* contains an interesting discussion on exactness and approximation.[99] There exist, according to him, two kinds of approximations (or inaccuracies). First are those that are imperceptible, being due to small variations in natural phenomenon that escape human perception, to instrumental errors, or to parallax. The second kind concerns perceptible quantities that are dependent upon the parameters involved. Such approximations are related to the methods employed, and al-Marrākushī says that he decided to include such approximate methods in his work, in parallel to the rigorous ones. The main virtues of approximation are obviously simplicity and rapidity of application. But another side to approximation concerns *universality*.

1.4.3 *Universality*

By definition, problems of positional astronomy depend upon the terrestrial latitude of the observer. Procedures, be they computational and numerical or graphical and instrumental, that are only valid for a particular latitude thus present a handicap in the field of timekeeping, since travels were by no means exceptional in medieval Islam. Already in the ninth century, the search for methods and instruments that can be used for any latitude represented an important part of timekeeping and instrumentation, which culminated for a first time in eleventh-century al-Andalus with the invention of successful univer-

[99] al-Marrākushī, *Jāmiʿ*, I, p. 3; Sédillot, *Traité*, pp. 59–60.

sal instruments, and again in the fourteenth century, during which universal instruments developed at an unparalleled pace.[100]

It is important to distinguish between two kinds of universal methods and instruments. The first kind results from the application of an *approximate* method, while the second kind is intrinsically universal in scope. All universal approximate methods and instruments are related to a formula for timekeeping of Indian origin, which expresses the time since sunrise or until sunset in seasonal hours τ in terms of the meridian altitude h_m and the instantaneous altitude h:[101]

$$\tau(h, h_m) = \frac{1}{15}\ \mathrm{arcSin}\left\{\frac{R\ \mathrm{Sin}\, h}{\mathrm{Sin}\, h_m}\right\}. \tag{1.1}$$

This formula provides, for intermediate latitudes, a fairly good approximation of the exact solution. We shall encounter in Najm al-Dīn's treatise numerous instruments, notably sundials, based on the application of this formula. In such cases, the scope of universality was limited to the inhabited world, which, it was thought, did not go beyond the seven geographical climates of Antiquity. Yet the main objective of Mamluk authors in *mīqāt* was to develop methods and to design instruments that are fully universal, without the cost of approximation. Operative universality – whether a particular instrument or method could be used to solve a wide range of problems (*li-jamīʿ al-aʿmāl al-falakiyya*) – was seen as equally important as geographical universality (*li-jamīʿ al-ʿurūḍ*). The introductions of Mamluk works on instrumentation reflect the obsession of their authors for universal solutions. Universality was a major virtue.

1.4.4 *Auxiliary tables*

Another major activity of *muwaqqit*s and *mīqātī*s was to compile numerical timekeeping tables. These, unless they were based on the universal approximate formula previously mentioned, were necessarily intended for a single terrestrial latitude. One could of course compile of set of tables for each degree of latitude within a given range, and this solution was indeed adopted by some *muwaqqit*s.[102] An alternative approach, inaugurated in the ninth and tenth centuries, consisted in the design and compilation of auxiliary tables that could be used to solve problems of spherical astronomy for any latitude. This tradition revived in the fourteenth century, notably with Najm al-Dīn al-Miṣrī.[103] I have presented in a previous publication a detailed analysis of his

[100] This topic is surveyed in King 1987b and idem 1988.

[101] The history of this formula and its applications is the object of a full-length essay: see King, *SATMI*, VII. Note that the formula is accurate at the equinoxes, and when $h = 0$ and $h = h_m$; it is also accurate for localities at the equator.

[102] See King, *SATMI*, I, § 9.9.

[103] See King 1987b, King, *SATMI*, I, § 9, and Charette 1998.

universal auxiliary tables, and these are again briefly described in Section 1.5, item 3.

1.4.5 *The use of lists of formulæ*

In ancient and medieval astronomy, formulæ were always communicated in a rhetorical way, without symbols. Learning them was a frustrating task, much different from reading modern mathematical formalism. No field features more formulæ than that of spherical astronomy, so each didactical treatise on *mīqāt* was bound to include a large amount of more or less complex trigonometric formulæ. The major Mamluk authorities on *mīqāt* were perfectly aware of the situation, and they introduced in their works a significant innovation to facilitate the memorizing and archiving of those formulæ in a compact manner. The innovation consists in noting down in each row of a table having four columns four quantities a, b, c, d for which the relation $a : b = c : d$ holds. al-Marrākushī is the first author to present such a table: his "Table of proportions" contains 62 entries. The 55th entry, for example, is equivalent to:
Cosine altitude : Cosine declination = Sine hour-angle : Cosine azimuth,
which corresponds to the modern formula $\cos a \ \cos h = \cos\delta \ \sin t$. al-Marrākushī proudly claimed that his table could replace many books, and that it eased memorization and allowed solving problems more quickly.[104]

Several successors of al-Marrākushī soon emulated his innovation. Najm al-Dīn inserted a similar table with 30 entries in an 'interlude' between the commentary on his universal auxiliary tables and his treatise on instruments, which is partially based on al-Marrākushī: it is edited in Part V and reproduced with modern symbolism in Appendix B. Some decades later Ibn al-Shāṭir continued the tradition by compiling such mnemotechnic tables for the benefit of his students. An early version with 154 entries is found in an appendix to a treatise on a kind of sine quadrant called *al-rubʿ al-kāmil* (MS Princeton Yahuda 373, ff. 181r–193r, on ff. 188v–193r). In his *Zīj* there is a similar table with 184 entries (MS Oxford Bodleian Selden A inf. 30, ff. 77r–82v). Other tables of this genre are also encountered in Mamluk and Ottoman manuscripts of *mīqāt*.[105] With such a formulary at hand, a student of *mīqāt* could use his sine quadrant without having to consult a very long treatise on its use.

In the modern historiography of mathematics these achievements are unknown. The importance of these early modern mathematical formularies should not be underestimated, for they certainly represent an important step away from the hold of the rhetorical and toward a greater symbolic abstraction.

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[104] al-Marrākushī, *Jāmiʿ*, I, pp. 180–183; Sédillot, *Traité*, pp. 351–359.

[105] E.g. in MS Dublin CB 4091, f. 15v and in MS Dublin CB 3651, f. 46r. On the former, see King, *SATMI*, II, § 10.3b.

1.4.6 *Didactical concerns*

A proper understanding of the tradition of *mīqāt* in particular and of Mamluk science in general is not possible without taking its educational context into account. Most of the technical astronomical or mathematical literature produced during this period was written with didactical purposes in mind, for the benefit of students who mostly did not aim at becoming professional astronomers. The fourth part (*fann*) of al-Marrākushī's *Jāmiʿ* is particularly revealing of the didactical concerns that motivated a first-rate astronomer to include materials of pedagogical relevance into his *opus magnus*. This fourth part consists of a quiz, a series of questions and answers, whose purpose is to promote skill and self-critique, in order to prepare the reader to work out the problems by himself.[106] This approach was also taken by Ibn Samʿūn[107] and Ibn al-Shāṭir; the latter concluded the longer version (in 200 chapters) of his treatise on the use of the instrument called *al-rubʿ al-tāmm* with a series of 100 questions and answers.[108]

1.5 *Najm al-Dīn al-Miṣrī*

Three documents attest to the existence of a specialist of *mīqāt* named Najm al-Dīn Abū ʿAbd Allāh Muḥammad ibn Muḥammad ibn Ibrāhīm al-Miṣrī:[109]

1. A short treatise on spherical astronomy entitled *al-Risāla al-Ḥisābiyya fī 'l-aʿmāl al-āfāqiyya* (Treatise on the universal operations [of time-keeping] by calculation), in 30 *bāb*s, and preserved in a single manuscript in Milan (Ambrosiana 227a, ff. 85v–97r).[110] Although the work is simply divided into 30 chapters, it is stated in the introduction that it comprises two parts (*fann*) devoted to *mīqāt*, the first of them being appropriate for beginners as well as for experts. Although this is nowhere stated, the 'second part' for experts can only correspond to the 30th chapter, which is a lengthy section with unnumbered divisions in which various problems are solved by means of the auxiliary function *aṣl*.[111]

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[106] al-Marrākushī, *Jāmiʿ*, II, p. 341.
[107] See King, *Survey*, no. C34.
[108] MS Cairo DM 138, ff. 34v–110v.
[109] On Najm al-Dīn, see Suter, *MAA*, no. 460 (where two different individuals are confused), King, *Survey*, no. C16, idem 1975a, pp. 44–45 and idem 1983a, pp. 540–541.
[110] It is attributed to "*al-Shaykh al-Imām al-ʿālim farīd dahrihi wa-waḥīd ʿaṣrihi Najm al-Dīn Abī ʿAbd Allāh Muḥammad ibn Muḥammad al-Miṣrī*". The manuscript was copied in 1386 by Aḥmad ibn Ibrāhīm al-Saṭḥī in the Mosque of Ibn Ṭūlūn in Cairo. It is catalogued in Löfgren & Traini 1975, p. 72; see also Charette 1998, p. 25.
[111] See Charette 1998, p. 28.

2. A short treatise on approximate methods of *mīqāt*, entitled *Ikhtiṣār al-maqāla fī maʿrifat al-awqāt bi-ghayr āla* (Abridgement of the treatise on finding the prayer times without an instrument), divided into 21 *bāb*s, and preserved in MS Istanbul Hamidiye 1453, ff. 228v–230r.[112].

   On ff. 219r–228v of the same manuscript is an anonymous treatise on the same topic with a related title: *Taḥrīr al-maqāla fī maʿrifat al-awqāt bi-ghayr āla*, which appears, however, to be by a different author (but also Egyptian, since he discusses the Coptic calendar). Despite their titles, which seem to imply that they derive from a common source, both texts are in fact independent.

   In the *Ikhtiṣār*, Najm al-Dīn presents simple approximate arithmetical procedures for solving timekeeping problems specifically for the latitude of Cairo. This work is of particular interest because it belongs to an intermediate level between primitive folk astronomy and advanced mathematical astronomy (cf. Section 1.4.1).[113] The introduction reads as follows:

   > قال الشيخ الإمام الفاضل المحقّق نجم الدين محمّد بن محمّد بن إبراهيم المصري رحمة الله عليه : لمّا رأيت كثيرًا من الناس يريدون أن يعلموا[ا] دخول وقت الصلوة مع وجود التمكين بمصر خاصّة وليس لهم يد في الحساب ولا لهم موضع يباشرونه فكتبت لهم هذه المقدّمة — « فإنّ العلم بالشيء تقريبًا خير من الجهل بالعمل تحريرًا »
   >
   > The excellent *shaykh* and Imām Najm al-Dīn Muḥammad ibn Muḥammad ibn Ibrāhīm al-Miṣrī (may God have mercy upon him) said: When I saw that several people who want to determine the beginning of the prayer times *maʿa wujūd al-tamkīn* [meaning unclear] for Cairo only are not skillful in calculation and do not have a place where they can carry it out, I decided to write this 'introduction' for them. — *Surely, knowledge of something by simple (approximate) methods is better than ignorance (of its application) by exact (and complicated) procedures.*

3. A huge set of tables covering 419 folios (with some lacunæ), extant in two codices which form the first and second halves of a single copy that was later split. The first half is MS Cairo, Egyptian National Library, Muṣṭafā Fāḍil *mīqāt* 132 (234 ff.), and the second half is MS Oxford, Bodleian Library, Marsh 672 (185 ff.).[114] We shall refer to these manu-

[112] This treatise is listed in Şeşen 1975–1982, III, p. 16. The manuscript was copied in Istanbul by ʿUmar ibn ʿUthmān al-Ḥusaynī al-Dimashqī, on 16 Rabiʿ II 759 [= Friday 4 April 1455]

[113] Its contents is summarised in King, *SATMI* II, § 2.5, together with the anonymous treatise.

[114] These tables were first identified by David King in 1973: see King 1975a; they were mentioned several times in later publications of his, such as King 1983a; cf. also Berggren 1986, pp. 181–182.

scripts with the *sigla* **A** and **B**. On the title-page of **B** the last words of a title can be read: ... *min ʿilm al-falak fī sāʾir al-āfāq* (the beginning has been erased),[115] and these tables are attributed to

الشيخ الإمام العالم جيّد دهره وفريد عصره نجم الدين أبو عبد الله محمد بن محمد المصري

The contents of these two manuscripts have been analysed in a previous publication, which includes an edition of the introduction.[116] In the main table, the time since rising T is tabulated in terms of three arguments, namely the half-arc of visibility D, the meridian altitude h_m and the instantaneous altitude h. With nearly 415 000 entries, this is the single largest mathematical table compiled before the late nineteenth century. There are also various other secondary tables accompanying the mammoth *Tables of Time-arc* (*jadāwil al-dāʾir*). The corpus also includes smaller tables covering the following topics: geography, chronology, trigonometry and spherical astronomy, solar and lunar motions, precession and fixed stars (see Appendix C).

David King has suggested that the Cairo-Oxford copy of the tables might be an autograph: this hypothesis, which I had omitted from my previous paper, is indeed not to be rejected, since one can hardly expect copyists to have embarked on the task of transcribing over 420 folios of densily written numerical entries; another argument speaking in favour of an autograph is that the Cairo-Oxford manuscript was copied before the year 736 H [= 1335/6], as attested by a gloss on f. 4v of the Cairo manuscript, that is, very shortly after the presumed date of compilation of the tables.[117]

There are also two anonymous items which can be attributed to Najm al-Dīn al-Miṣrī:

4. An (anonymous) commentary on the use of these tables in 130 chap-

[115] The word *ʿilm* might be spurious, since one would actually expect the following title: *Jadāwil al-Dāʾir min al-falak fī sāʾir al-āfāq*.

[116] Charette 1998, esp. pp. 19–23 (description of the manuscripts). In my description I have omitted to notice two codicological details of MS **A**, namely, (1) that it is foliated with Coptic numerals (certainly after the original manuscript was split), and (2) that on f. 15r there is a notice of possession which reads *fī nawbat al-faqīr Ḥasan al-Jabartī al-Ḥanafī, ghafara lahu*; on this individual (d. 1774 AD) – the father of the Egyptian historian ʿAbd al-Raḥman al-Jabartī – see Ihsanoğlu, *OALT*, II, pp. 472–479 and King, *Fihris*, s.v. in the indexes of authors and owners.

[117] In Charette 1998, p. 17, I made the remark that there must have existed multiple copies of the tables, since in Ch. 72 of Najm al-Dīn's commentary there is a note which warns against possibly corrupted copies of the tables. I now consider this as a statement of a theoretical nature by the author himself, rather than a later interpolation motivated by a copyist's encounter with a corrupt version of the tables.

ters,[118] extant in MS Dublin, Chester Beatty, Persian 102, ff. 1r–24r – which we designate as **D**. In this commentary the author explains how to use Najm al-Dīn's tables (3) as universal auxiliary tables for solving all problems of spherical astronomy for all terrestrial latitudes. It has been analysed in detail in a previous publication of mine.[119]

In the introduction of (3), Najm al-Dīn says that he has prepared additional problems or operations (*aʿmāl*) useful to the experts and that he placed them "at the end of the book".[120] The tables in MS **B** end abruptly within a sine table, but the instructions in the Dublin manuscript correspond very well with Najm al-Dīn's reference. A more decisive argument in favour of Najm al-Dīn's authorship of this commentary is provided by the identity between a passage in it and his treatise on spherical astronomy (1): Chapter 26 of (1) is indeed textually reproduced within Chapter 128 of (4) [**D**:23v:19–24r:7].[121]

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[118] Since Chapter 129 is omitted, there is in fact a total of 129 chapters, and although 'Chapter 129' is listed in the table of contents on f. 2v, no title is given.

[119] See Charette 1998, esp. pp. 27–41. The relationship of (4) with Najm al-Dīn's tables (3) was first noted in King 1993, on p. 10 of the "Addenda and corrigenda".

[120] See Charette 1998, p. 50 and translation on p. 42, § [4].

[121] Both texts are here reproduced for comparison. First treatise (1) (MS Milan ff. 92:11–93:5):

الباب السادس والعشرون في معرفة العرض والبعد من قبل الغاية ونصف القوس. انسب جيب الغاية من سهم نصف القوس وخذ بمثل تلك النسبة من س واحفظه. ثم خذ الفضل بين المحفوظ وبين جيب الغاية وزده على المحفوظ إن كان جيب الغاية أقلّ من المحفوظ، وانقصه من المحفوظ إن كان جيب الغاية أكثر من المحفوظ. فإن [كان ال]اجتمع أقلّ من س فهو جيب غاية النظير، وإن اجتمع أكثر من س فالمسألة لا يمكن وجودها. ثم خذ الفضل بين غاية النظير والغاية الأولى، فما بقي خذ نصفه، فهو البعد إن كان (!) جهة الغاية شمالية عن سمت الرأس، والعرض إن كان (!) جهة الغاية جنوبية عن سمت الرأس. وإن كان جيب الغاية أكثر من سهم نصف القوس فالغاية لا يمكن وجودها ...

Then the corresponding passage in (4) (**D**:23v:19–24r:7):

الباب الثامن والعشرون ومائة في معرفة العرض والبعد من قبل الغاية ونصف القوس. ادخل بالغاية في جدول الجيب وخذ ما بإزائه فهو جيب الغاية. ثم ادخل بنصف الفضلة في جدول الجيب وخذ ما بإزائها، زده على س إن كان نصف القوس أكثر من ص ، وانقصه من س إن كان نصف القوس أقلّ من ص ، فما بقي فهو سهم نصف القوس. ثم انسب جيب الغاية من سهم نصف القوس وخذ بمثل تلك النسبة من س واحفظه وخذ الفضل بينه وبين جيب الغاية، زده على المحفوظ إن كان جيب الغاية أقلّ من المحفوظ، وانقصه من المحفوظ إن كان جيب الغاية أكثر من المحفوظ، فما حصل بعد ذلك، إن كان أكثر من س فالمسألة محال وهو الذي أهدرناه في كتابنا هذا، وإن كان س فاقد (؟) فهو جيب غاية النظير وهو الذي آتيناه في كتابنا. ثم خذ الفضل بين غاية النظير والغاية الأولى. فما كان خذ نصفه، فتارة يكون العرض وتارة يكون البعد. بيانه: إن كانت جهة الغاية شمالية عن سمت الرأس فالخارج هو العرض، وإن كانت جنوبية عن سمت الرأس فالخارج هو البعد. واعلم أن ما ذكرنا النسبة في هذا الباب إلّا لأجل إقامة الدليل على أنصاف القسي والغايات المثبوتة في كتابنا هذا والمهدور منه. فأردت أذكر بابه لتعلم (ليعلم في الأصل) كيفية استخراج أنصاف القسي المركّبة على تلك الغايات. واعلم متى كان جيب الغاية أكثر من سهم نصف القوس فالمسألة محال.

It seems that the latter text is an adaptation of Chapter 26 in (1) for the purposes of (4).

5. An extensive (anonymous) illustrated treatise on the construction of instruments which forms a continuation of (4) and is clearly by the same author (see the next Section for a detailed discussion). This is the main source for the present study.

Remarks on the dating of the above works. The composition of (3) can be estimated to within the period *ca*. 700–730 H [= 1310–1330], and the commentary (4) must have been composed shortly thereafter.[122] In (4) and (5), Najm al-Dīn mentions the name of al-Marrākushī with a eulogy ("may God have mercy upon him") used only for deceased Muslims. al-Marrākushī died after 680 H [= 1281/2]. A *terminus post quem* for the instrument treatise (5) is the year 723 H [= 1323], which is mentioned in (5), cf. p. 247. This treatise, which is dependent upon (3) and (4) and forms the second part of (4), was thus probably composed within the period *ca*. 725–740 H [= 1325–1340].[123]

1.5.1 *The authorship of the instrument treatise*

When David King discovered the treatise on instruments in the Dublin manuscript in 1982, he was immediately convinced that its author was Ibn al-Sarrāj, a Syrian astronomer and mathematician active in the first half of the fourteenth century.[124] Since then and until 1999, this treatise as constantly been referred to by the same author as a work by Ibn al-Sarrāj.[125] There were two good reasons for this attribution. First, the great majority of the instruments illustrated in the treatise are designed for a latitude of 36°, which, in a Mamluk context, corresponds to Aleppo, where Ibn al-Sarrāj spent most of his active life.[126] Second, in the Dublin manuscript there is an illustration of a universal astrolabe of a type similar to the one known to have been 'invented' by Ibn al-Sarrāj. At the beginning of the chapter corresponding to this illustration, the author says that he invented the instrument in Mecca in the year of his stay there, namely, 723 H. Since there is preserved a (more complex) universal astrolabe made by Ibn al-Sarrāj in the year 729 H, the attribution to him seemed secure.

A closer look at the manuscript, however, reveals a marginal note by the scribe of manuscript **D** next to the above-mentioned illustration, saying that

[122] The *terminus post quem* is suggested by Najm al-Dīn's mention of the timekeeping tables of Shihāb al-Dīn al-Maqṣī (see Section 1.3.1), a Cairene *mīqātī* contemporary of al-Marrākushī, in the introduction of (3). Furthermore, the work cannot have been composed after 736 H, since MSS **A+B** have been copied before this date.
[123] The (approximate) *terminus ante quem* for (5) is given on the basis of internal evidence: several instruments which were well-known to Egyptian and Syrian specialists of *mīqāt* by the middle of the fourteenth century are not featured in it.
[124] See King 1987c, p. 2.
[125] In King 1999, p. xxix, Ibn al-Sarrāj's proposed authorship is retracted.
[126] See Section 1.3.4.

the latter was drawn there by mistake, and that it actually belongs to the previous chapter. Hence the instrument which the author invented in Mecca is in fact a universal plate which is unrelated to Ibn al-Sarrāj's astrolabe. In Ch. 9, where the universal astrolabe related to Ibn al-Sarrāj is featured, the author declares that the instrument, which he calls *shajjāriyya* (see Section 2.6.4), is a Byzantine invention! The only convincing evidence in favour of Ibn al-Sarrāj has thus vanished.

In the course of studying MS **D**, I soon realised that there was a close link between the commentary on Najm al-Dīn's tables and the instrument treatise which follows it. I finally arrived at the conclusion that the whole must be by one and the same author. Since I have already shown that the commentary on the universal tables on ff. 1-24 is by Najm al-Dīn himself, the instrument treatise must then be also attributed to him. In order to establish the evidence for this attribution, it is necessary to present a detailed description of MS **D** and of the relationship between 'Part 1', containing the commentary on Najm al-Dīn's universal tables, and 'Part 2', containing the instrument treatise.

The commentary on the use of Najm al-Dīn's universal tables ends with Chapter 130 on f. 24r. This is immediately followed by the words: "The *Shaykh* – may God be pleased with him – said: The chapters on the operations (with the tables) are finished, with the help of God full of Majesty." The eulogy employed indicates us that the copy was made during the author's lifetime. There follows a summary appreciation of the commentary. On f. 24v we find a table "of declinations and equations" (also announced on the last line of the recto); it is in fact an auxiliary function for timekeeping which has nothing to do in this treatise.[127] On f. 25r begins a section which forms a kind of 'interlude', again with a formula introducing the words of the author and with the same eulogy. The text on this page explains the use of the 'Table of Proportions' found on the next two pages (ff. 25v–26r), one half of which is attributed to al-Marrākushī (who is mentioned as a deceased scholar).[128]

Then, on ff. 26v–27r, the same unnamed author (here qualified as *al-shaykh al-imām al-ʿālim al-ʿallāma, waḥīd dahrihi wa-farīd ʿaṣrihi*) continues to discuss the use of his tables, adding that arithmetical operations and auxiliary quantities are not required. The author – who can only be Najm al-Dīn – then introduces two kinds of tables he has compiled for the purpose of constructing instruments. The first category concerns the construction of altitude and azimuth markings on astrolabes and related instruments. These are compiled according to the instructions in various chapters of the commentary on the universal tables. The second category concerns various types of sundials, and Najm al-Dīn again refers to the above commentary. On f. 27r we finally find a table of the first kind described, which serves for constructing astrolabe

[127] See Appendix 1.
[128] These tables are further discussed in Appendix B.

markings for latitude 36°. Until this point the codex has been copied in the same *naskhī* hand along red-ink rules. The next folio (27v) was originally blank,[129] and on f. 97v (originally f. 28r: the manuscript was later bound in disorder), there begins the second part of the codex copied by a different hand (but on the same thick ivory-colored paper), containing a lengthy and richly-illustrated treatise on the construction of various instruments. Already in the first chapter of this second part we find indications that the instrument treatise is in fact a continuation of the first part described above. There are two references to "a procedure (*faṣl*) in the last of the chapters", that is, Ch. 130 of Part 1, which indeed deals with astrolabe construction. There is also a reference in Ch. 1 to "the table on the back of this page", which is on f. 27r. This table is actually implicitly referred to in all of the chapters of the instrument treatise which deal with the construction of astrolabe markings for a latitude of 36°.

In the introduction to his universal tables, Najm al-Dīn promises that he will not burden the expert in the instructions on the use of the table with any arithmetical operation like multiplication, division and root extraction.[130] In the conclusion to the commentary (**B**:24r), Najm al-Dīn makes a summary statement about whether he has succeeded in this respect, and says that in 127 out of 130 chapters he has not referred to these operations at all, and that in the other three these were absolutely necessary. All this is also repeated on **D**:26v, where the author recapitulates the material he presented and then explains how he compiled the tables for instrument-making. Similar remarks where the author expresses regret for having used arithmetical operations are also expressed in the instrument treatise that follows (see Ch. 60, the end of Ch. 115 and Ch. 102 on p. 329). There is also a reference in Ch. 60 of the instrument treatise to the "Tables of proportions which are mentioned at the beginning", that is, the two tables on **D**:25v-26r. Other chapters in the instrument treatise contain explicit references to the *Jadāwil al-Dāʾir*, i.e., to Najm al-Dīn's universal tables, and also to other tables contained in MSS **A** and **B**. Furthermore, upon investigation of the tables in the instrument treatise, it turns out that *all* of them are indeed based on Najm al-Dīn's tables. The various sundial tables, which correspond very well with those announced in the introduction (**D**:26v), turn out to make exclusive use of Najm al-Dīn's Cotangent table preserved in manuscript **B**.

Finally, it should be noted that whilst latitude 36° is predominant in the treatise (most tables and most illustrations of instruments being for this latitude), there are no specific references to Aleppo in the text. But one finds direct references to Cairo on some occasions (Chs. 10, 84, 91 and 93). There are also a few instruments illustrated which are designed for the latitude of Cairo, namely, 30° (Chs. 65 and 66). In addition, Ch. 91 provides instruc-

[129] See p. 32 below.
[130] See Charette 1998, p. 50 and the translation on p. 42, § [4].

tions for constructing the base of the ventilator (*bādahanj*), a common feature of Cairene architecture, and these instructions are only valid for the region of Cairo. These indeed confirms the fact that the author was Egyptian. But nothing precludes Najm al-Dīn, who is presumed to have spent most of his active life in Cairo, from having sojourned for some time in Aleppo or to have been commissioned to compose a treatise for someone in that city.[131] Another possibility would be that he chose the latitude of 36° as a purely didactical example for the fourth climate.[132]

One last point: the known treatises of Ibn al-Sarrāj – mostly short works on instruments – are written in a technical Arabic that is incisive and precise. The Arabic of this instrument treatise has neither of these features. The text is occasionally a little confused and quite colloquial in style (see Section 1.5.3), and in this it is comparable to the introduction to Najm al-Dīn's tables. However, the other two treatises by Najm al-Dīn (1 and 2), even though they present some features of Middle Arabic, are written in a more elaborate style.

In view of the above evidence, there should be no doubt that Najm al-Dīn al-Miṣrī ought now be considered as the author of the whole of MS **D**. I shall now present a codicological description of this manuscript as well as of a second one which has become accessible to me during the course of my investigation.

1.5.2 *Description of the manuscripts*

1. Dublin, Chester Beatty Library, Persian 102

This manuscript, after it was bought by Sir Alfred Chester Beatty, was integrated into the Persian collection on the basis of a spurious colophon, and it was thus recorded under the *Catalogue of Persian Manuscripts and Miniatures*, where it was labelled, however, "An Arabic Treatise on the Astrolabe", and dated to *ca*. 680 H.

The leaves measure 28.0 × 20.2 cm. The paper is thick, non-polished and of an ivory tone. The binding is of dark chestnut leather, with an almond-shaped central motif and four blind-tooled corners with floral background of Persian style. (For the rest of the description we shall consider the manuscript in two separate parts, which are the works of distinct copyists.)

Part 1 (ff. 1-27). The written surface measures 24.7 × 18.2 cm, with 25 lines per page. The writing is in a clear *naskhī* hand (I shall denote this copyist by the label C1). The text is surrounded by a red frame and written along red-

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[131] No doubt there were scholars in Aleppo in that period who were interested in the topic, especially in the entourage of Ibn al-Sarrāj.

[132] Interestingly, the examples in al-Bīrūnī's *Istīʿāb* are also for a latitude of 36°, even though he composed the work in Gurganj (latitude 42°17′). The value 36° corresponds to the middle of the fourth climate (at least with Ptolemy's value of the obliquity).

ink rules ("a style found only in very old books"[133]), with chapter headings in red ink, as well as the expressions وقد and وأمّا within the chapters. The tables on 25v-26r and 27r are likewise written in red (a few entries being in black).

Part 2 (ff. 28-99). In the second part the written surface has essentially the same dimensions as in Part 1. The writing is a characteristic, very cursive *naskhī* throughout, which can be seen e.g. on Plate 4. The text on ff. 98, 99 and 96 and the legends of several illustrations, however, are by a third copyist, whose handwriting is a meticulous, small, 'square' *naskhī*, carefully dotted and vocalised (the paleographic features are best illustrated on Plate 9; the caption of the illustration displayed on Plate 10, showing an interesting ornamental 'kufic' script, is also by this third copyist). I shall denote the main copyist of Part 2 by the *siglum* C2 and the third one by C3. Chapter headings are likewise in red ink. There are large illustrations or tables on each single folio except 97r and 37v, for a total of 142 diagrams[134] in black and red ink (the diagram on f. 45v also has strips of gold ink) and 16 tables (counting that on f. 27v, which belongs to Ch. 1). Many of the diagrams in the first 55 chapters are left partially unfinished, and in some cases only the most basic markings are drawn. This is the case for the following chapters (whereby the superscript '1' following the chapter number refers to the first half of the chapter, and '2' to its second half, in those cases where a chapter has two illustrations on two consecutive pages):[135]

> 5–8, 10, 12, 13^2, 15^2, 18^1, 19^1, 20^1, 21^1, 22^1, 23^1, 24^1, 27^1, 28^1, 29, 31, 32, 33^1, 34^1, 35^1, 36^1, 37^1, 38–42, 44–50, 53–55.

For the rest of the treatise, which is only extant in **D**, the diagrams of Chapters 84 and 95 also seem to be incomplete.

The folios of Part 2 are in severe disorder. The correct, original foliation corresponds to ff. 97-99, 96, 78-85, 38-46, 57-77, 86-95, 47-56, 37, 31, 28-30, 32-33, 36, 34-35. Folios 37 and 58 have been bound in reverse (verso before recto).

On ff. 27v and 28r, that is, between the first and second parts, there is a splendid illumination richly decorated in gold and blue which fills the double page. It surrounds a text which purports to serve as a colophon:

تمّت (!) المجلّد الأوّل / الكتاب (اقرأ: للكتاب) في علم الاسطرلاب / ويتلو[136]

[133] E. B[lochet] and M. M[inovi] in Arberry, *Catalogue*, I, p. 3. One should note, however, that the text on f. 1r of MS **A** is also written on rules. See also p. 34, n. 1.5.2 below.

[134] Each drawing of an independent component of a given instrument, such as its plate or rete, counts as a diagram. Also counted are the incomplete drawings on ff. 97v and 99v, which are repeated elsewhere.

[135] In general, the illustration in the first half is that of an astrolabic plate, and that in the second half shows the corresponding rete.

[136] و is at the end of the preceding line.

مجلّد الثاني (اقرأ: المجلّد الثاني) من تصنيف / [28:r] إمام (اقرأ: الإمام) العالم أبو (!) الحسن / نشابوري رضي الله عنه في شهر / رجب سنة اثنى وعشرون (!) وخمس مايه /

أحمد اليهفي (اقرأ: البيهقي)

> The first part of the book on the astrolabe ends. It is followed by the second part, composed by the learned Imām Abu ’l-Ḥasan Nīshāpūrī (may God have mercy upon him) in the month Rajab of the year 522 [= July 1128 AD]. Aḥmad al-Bayhaqī.

This is obviously a fabrication by an Iranian who had a limited command of Arabic: the few lines above reveal at least eight grammatical mistakes. The forger used two folios that were originally empty, and since those two folios came to face each other only after the book had been rebound in disorder, this suggests that either his forgery occurred thereafter, or that he himself is responsible for the chaotic rebinding. The names of the purported author and copyist mentioned on this colophon were probably inspired by famous Persian figures like the Qur’ānic scholar al-Ḥasan al-Nīshāpūrī (d. 1016) and the *shīʿī* author Abū Bakr Aḥmad al-Bayhaqī (d. 1066), even though they died several decades before the purported date of copying. In the Dublin catalogue, Blochet and Minovi signal a very similar deception by the same Iranian forger in a manuscript in the British Library (Or. 7942).[137] The same forger also pasted on the upper margin of ff. 1r and 25r two strips of olive-colored paper (originally gold) bearing a decorative *basmala* written in light green ink.

Owners’ stamps Two seals are stamped in the left margin of f. 1r. One of them is a stamp of ownership, accompanied by a smaller one on which we read the following atypical combination of two common religious pronouncements:

ما شاء الله لا قوة إلّا بالله

> What God wills (is what will be). No strength (is gained) but through God!

The stamp of ownership reads as follows:

من متملّكات الفقير الحاجّ مصطفى صدقي غفر له ١٧٩

> From the possessions of the wretched (slave of God) *Ḥājj* Muṣṭafā Ṣidqī (may [God] forgive him) – [1]179 [= 1765/66 AD].

[137] Arberry, *Catalogue*, p. 2, note.

This individual is the Ottoman scholar Muṣṭafā Ṣidqī ibn Ṣāliḥ (d. 1183 H [= 1769]), who is well known as a copyist of precious mathematical texts and an able mathematician himself;[138] he owned an impressive scientific library, a reconstruction of which is underway by the present author which will be included in a future publication.[139] Another Ottoman seal, oval in shape and smaller in size, with floral background, is found on f. 2v. Two circular seals – illegible, but different from the above ones and probably identical to each other – have also been stamped in the lower margin of f. 89r.

2. Private collection

A second, incomplete copy of the same treatise became known to the present author in the late 1990s. It was auctioned at Christie's (London) on April 11, 2000. Its present location is unknown, but rumour has it that it could be in Qatar. This manuscript, which I shall henceforth designate with the *siglum* **P**, contains slightly more than one half of the contents extant in **D**. It has been recently (*ca.* 1998) rebound and paginated with modern Arabic numerals. Until then it was bound together with an Ottoman Egyptian *taqwīm* (ephemeris). The 38 folios of the instrument treatise were previously bound in considerable disorder. The recent rebinding has restored the correct ordering, but it has also destroyed its codicological history.

The following physical description of the manuscript is based on the entry in the Christie's sales catalogue.[140] The leaves measure 25.7 × 19.5 cm. The paper is of buff colour with light staining and smudging. The handwriting is a clear but not so elegant *naskh* in sepia ink. The text is written on red rules and the pages are surrounded by a red frame.[141] The binding is a "contemporary brown morocco with geometrical tooled decoration, restoration at spine, rather scuffed".[142] The illustrations, drawn in red and sepia inks, are all complete. They have exactly the same format as in **D**, and are generally even more accurately executed. Recent pagination (1–76) in pencil in a modern Arabic hand was made after rebinding. The 38 folios of this manuscript span the first 76 chapters of the treatise, with numerous lacunæ (the beginning is lacking and then 11 folios appear to be missing; see the table of concordance below).

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138 See Ihsanoglu, *OALT*, II, pp. 466-467, and King, *Survey*, no. D81.

139 A report on my work-in-progress on Muṣṭafā Sidqī's library was presented at the annual congress of the German Middle East Studies Association for Contemporary Research and Documentation in Hamburg in December 1999 (listed as Charette 1999 in the bibliography).

140 Christie's, London, *Islamic Art and Manuscripts, 11 April 2000*, lot 22, pp. 14–17.

141 This feature is comparable in style to the first part of **D** and to the first page of **A**. It is probably an indication that those manuscripts originate from similar milieus, that is, mid fourteenth-century Cairo.

142 Christie's Catalogue, p. 14.

Relationship between the manuscripts

During completion of my critical edition of Najm al-Dīn's treatise on the basis of the above two manuscripts, it became progressively obvious that **D** was a direct copy of **P**. My suspicion was aroused by noticing that **D** featured many more omissions than **P**, including whole lines of text. Such lacunæ are also noted in the parts of the treatise where **D** is the unique source. More specifically, there are 42 occurrences of omissions in **D**, and only 6 in **P**. The latter are short words which the copyist of **D** may have interpolated as natural emendations. The fact that all illustrations in **P** are complete, whereas many of them have been left unfinished in **D**, also strengthened my suspicion. A decisive proof of the direct dependence of **D** upon **P** is found in Ch. 43, where the copyist of **P** omitted two series of words at two places on a single line of text and then wrote the missing words sideways in the margin, one above the other, after having marked the respective positions of the two lacunæ in the line where the marginal corrections have to be inserted. But there is nevertheless an ambiguity, since it is not obvious to any reader of **P** which marginal correction corresponds to which lacuna on this line of text. One would naturally be tempted to associate the *upper* marginal correction to the *first* lacuna, and the *lower* correction to the *second* lacuna, but in fact the correct correspondence is rather the reverse! This indeed induced the copyist of **D** to insert each marginal correction at the wrong place in the text, so that the corresponding passage in this copy does not make any sense. Other examples illustrating the direct dependence of **D** upon **P** can be given: On the illustration of an astrolabe rete in **P**:31r, the star names accompanying two star-pointers have been smudged, so the copyist decided to write them a second time below the circumference of the rete, vis-à-vis their respective pointers. On **D**:40v the same two star-pointers are unlabelled, but the star names appear below the circumference exactly in the same position as in **P**![143]

Also very eloquent for the dependence of **D** upon **P** are the scribal errors in the tables of Chs. 61 and 76 (see the apparatus to these tables in the edition). One typical error of transcription of the copyist of **D** was to read لب as ل, which given the paleographical characteristics of **P** is a very easy mistake to make. At another place the number كب in **P** looks like a ى and was interpreted as such by the copyist of **D**.

Table of concordance

In Table 1.1 (p. 37), a general concordance between manuscripts **D** and **P** is given, following the logical order of the work. Since each chapter fills either one or two pages, I use for each page containing one half of a chapter a superscript after the chapter number to indicate its first or second half. For

[143] See the apparatus of the edition of the text in the second illustration in Ch. 19, under the star names [رأس ا]لحوّاء and عقاب.

manuscript **P** I give the former foliation as well as its recent pagination in brackets.

1.5.3 *A general appreciation of Najm al-Dīn's instrument treatise*

The treatise on instruments preserved in manuscripts **P** and **D** is unique of its genre. First, it is exceptional in virtue of the number, size and quality of the illustrations it features. Of the 140 pages[144] of manuscript **D**[145] which are effectively used to display the contents of the 120 extant chapters, only 8 pages are devoid of any illustration. We find in fact no less than 139 different diagrams, most of them occupying *ca.* two thirds of a page. In manuscript **D** I count a total of approximately 1250 lines of text distributed among 140 pages. Since text only would fill 30 lines per page (as on f. 97r), this means that we have in this manuscript the equivalent of 42 pages of text out of 140. In other words, the text of Najm al-Dīn's treatise accounts for around 30% of the whole manuscript, the rest being made up of plentiful illustrations and some tables.

For historians of scientific instruments it is also a work of great interest since it includes descriptions of instruments which are otherwise absent from the Arabic technical literature, or hitherto insufficiently documented.

The text presents plainly technical instructions on how to construct a large variety of instruments by ruler and compass, many of them according to unusual methods that are unique to the author. These instructions concentrate exclusively on the *mathematical* aspects of the construction, and in general ignore its more practical details, the knowledge of which being implicitly assumed from the reader. For example, not a single word is devoted to the construction of accessory elements of instruments, like alidades and sights. Also, there are no explanations of the technical terminology.

In most cases the text hardly makes sense alone, and the accurate illustrations of the instruments are indispensable to its understanding. In general it can be said that the author consciously reduced the textual information to a minimum in order to convey as much as possible through visualization. Yet many of the instructions are obscure or elliptical, and one can hardly assume that a beginner would have been able to use this illustrated treatise as a manual for independent study.

The text does not contain any discussion of a theoretical nature,[146] and

[144] Excluding 4 pages (ff. 98v, 99v, 27v and 28r) featuring either repeated illustrations or the spurious colophon.

[145] For the first half, the portions extant in **P** have the same layout as **D** and the page correspondence is the same.

[146] In principle, the only theory needed would concern stereographic projection and gnomonics, two subjects dealt with in detail by al-Marrākushī. The absence of theoretical material in Najm al-Dīn's treatise should thus be seen as perfectly normal and fully in accordance with the nature and purpose of the work.

TABLE 1.1. Table of concordance between manuscripts **D** and **P**

Ch.	D	P	Ch.	D	P	Ch.	D	P
1^1	97r	–	34^1	62r	4v (36)	77	94v	–
1^2	97v-98r	26r (1)	34^2	62v	19r (37)	78^1	95r	–
2	98v	26v (2)	35^1	63r	19v (38)	78^2	95v	–
3	99r-v	16r (3)	35^2	63v	36r (39)	79^1	47r	–
4^1	96r	16v (4)	36^1	64r	36v (40)	79^2	47v	–
4^2	96v	14r (5)	36^2	64v	21r (41)	80	47v	–
5	78r	14v (6)	37^1	65r	21v (42)	81	48r	–
6	78v	–	37^2	65v	–	82	48r	–
7	79r	–	38	66r	–	83	48v	–
8	79v	–	39	66v	5r (43)	84	49r	–
9^1	80r	–	40	67r	5v (44)	85	49v	–
9^2	80v	15r (7)	41	67r	5v (45)	86	50r	–
10	81r	15v (8)	42	67v	29r (46)	87	50v	–
11	81v	17r (9)	43	68r	29v (47)	88	51r	–
12^1	82r	17v (10)	44	68v	33r (48)	89	51v	–
12^2	82v	25r (11)	45	69r	33v (49)	90	52r	–
13^1	83r	25v (12)	46	69v	27r (50)	91	52v	–
13^2	83v	–	47	70r	27v (51)	92	53r	–
14^1	84r	–	48	70v	–	93	53v	–
14^2	84v	22r (13)	49	71r	–	94	54r	–
15^1	85r	22v (14)	50	71v	–	95	54r	–
15^2	85v	24r (15)	51	72r	–	96	54v	–
16	38r	24v (16)	52	72v	28r (52)	97	55r	–
17	38v	–	53	73r	28v (53)	98	55r	–
18^1	39r	–	54	73v	34r (54)	99	55v	–
18^2	39v	–	55	74r	34v (55)	100	55v	–
19^1	40r	–	56	74v	30r (56)	101	56r	–
19^2	40v	31r (17)	57	75r	30v (57)	102	56v	–
20^1	41r	31v (18)	58	75v	6r (58)	103	37v(sic)	–
20^2	41v	32r (19)	59	76r	6v (59)	104	37v(sic)	–
21^1	42r	32v (20)	60	76v	7r (60)	105	37r(sic)	–
21^2	42v	–	61^1	77r	7v (61)	106	31r	–
22^1	43r	–	61^2	77v	–	107	31v	–
22^2	43v	–	62	86r	–	108	28v-29r	–
23^1	44r	–	63	86v	8r (62)	109	29v	–
23^2	44v	23r (21)	64	87r	8v (63)	110	30r	–
24^1	45r	23v (22)	65^1	87v	9r (64)	111	30v	–
24^2	45v	1r (23)	65^2	88r	9v (65)	112	32r	–
25	46r	1v (24)	66	88v	10r (66)	113	32v-33r	–
26	46v	2r (25)	67	89r	10v (67)	114	33v	–
27^1	57r	2v (26)	68	89v	11r (68)	115	36r	–
27^2	57v	20r (27)	69	90r	11v (69)	116	36v	–
28^1	58v(sic)	20v (28)	70	90v	12r (70)	117	–	–
28^2	58r(sic)	35r (29)	71	91r	12v (71)	118	–	–
29	59r	35v (30)	72	91v	13r (72)	119	34r	–
30	59v	18r (31)	73	92r	13v (73)	120	34v	–
31	60r	18v (32)	74	92v	37r (74)	121	35r	–
32	60v	3r (33)	75	93r	37v (75)	122	35v	–
33^1	61r	3v (34)	76^1	93v	38r (76)			
33^2	61v	4r (35)	76^2	94r	38v (77)			

historical information is provided only sparely. Only two of Najm al-Dīn's predecessors are occasionally mentioned, namely al-Bīrūnī (in Chs. 12, 24, 37, 38) and al-Marrākushī (in the introduction and in Chs. 101, 102). It is also very important to note that Najm al-Dīn's generally comprehensive illustrated survey omits most of the instruments that were invented by his contemporaries Ibn al-Sarrāj, Ibn al-Ghuzūlī and Ibn al-Shāṭir.[147] Also, the way to *use* the instruments featured is never discussed.[148]

Najm al-Dīn's style is rather poor and his Arabic quite colloquial: this characteristic is examined in Section 1.5.3.

The structure of the treatise, in its successive discussion of different categories of instruments, roughly correspond to the following scheme:

- the planispheric astrolabe and variations thereof (38 chapters);
- the spherical and linear astrolabes (2 chapters, dispersed);
- astrolabic quadrants (15 chapters);
- horary quadrants and dials (15 chapters);
- trigonometric instruments (3 chapters);
- observational instruments (3 chapters, dispersed);
- portable and azimuthal sundials (17 chapters);
- fixed sundials (24 chapters);
- miscellaneous (3 chapters, dispersed).

Although the general ordering of the chapters agrees with the above, many of them are illogically placed and do not respect the general scheme.

A judgement of its merits

In general, the text leaves the impression of having been composed rather spontaneously, or even hastily, and for the sole use of a limited circle of students or colleagues. It is highly repetitive in places, especially the chapters on astrolabes and astrolabic quadrants, which account for nearly one third of the whole. Some passages burst of enthusiasm, others are astonishingly naive. In some cases Najm al-Dīn's occasional enthusiasm and ingenuity turns into something which could be better characterised as imbecility. Yet this judgement of mine should not be taken *à la lettre*, for this unique historical document gives us fascinating insights into the scientific practice of an accomplished yet rather eccentric specialist of *mīqāt*.

[147] I have mentioned the inventions of these personalities only in passing whenever it seemed relevant to the present study. For general references see Section 1.3 above. See also the remarks on p. 209.

[148] There is one minor exception to this rule: at the end of Ch. 49 there is a discussion of a special aspect of the use of the astrolabic quadrant, which, unfortunately, makes very little sense.

For whom was it written?

This treatise of Najm al-Dīn belongs to a completely different category of technical literature than the works of his better-known contemporaries al-Mizzī, Ibn al-Sarrāj or Ibn al-Shāṭir, which were specifically written for didactical purposes. These are treatises on the *use* of instruments. Yet it is difficult to exactly identify Najm al-Dīn's intended audience, which is certainly not made up of mathematically well-versed readers, since the author explicitly sets himself the goal of avoiding having recourse to arithmetical operations, which he achieves by presenting tailor-made numerical tables (or explaining how similar tables can be compiled without computation with the help of the author's universal auxiliary tables).

I have noted above that the treatise could have hardly been intelligible to beginners, since it assumes a considerable amount of technical knowledge on instruments. It could possibly have been used as a *reference manual* for teaching intermediate students. In this sense, Najm al-Dīn's illustrated handbook could have been very useful, as it provided within one book canonical representations of a vast array of instruments.

The illustrations in both manuscripts

Manuscript **P** contains 73 large-format illustrations in black and red, occupying two-thirds to three-quarters of the lower portion of almost each page. All illustrations are complete. The second part of **D** (ff. 28–99 = 144 pages) features 139 diagrams in the same format, out of which at least 41 were left unfinished.

In general the copyists have carefully executed the diagrams, manifestly constructing the instruments according to the mathematical rules explicated in the text, a very uncommon feature of Mamluk scientific manuscripts and a rare characteristic of Islamic scientific manuscripts in general (see below).[149] This indicates that both copies were probably executed by individuals temporally and spatially close to the author. Perhaps they were students of his, or copyists working in close proximity to him. It is difficult to make a general statement about the illustrations in Najm al-Dīn's original treatise, but they can hardly have been superior to those found in **P**. Some particularly fine illustrations selected from both manuscripts are reproduced on Plates 1–18. A facsimile edition of both manuscripts is in preparation at the Institut für Geschichte der Arabisch-Islamischen Wissenschaften, Frankfurt am Main.

Taken together, these two manuscripts represent the finest corpus of illustrations of instruments within a single treatise that is known from the Islamic scientific tradition. Their illustrations are comparable in quality and richness to the major illustrated treatises on mechanics such as those of the Banū

[149] Of course many specific markings are not necessarily accurate, but in general the *intention* to produce *metrical* illustrations is clearly felt.

Mūsā, al-Jazarī and Ibn Khalaf al-Murādī.[150] In the field of instrumentation the work surpasses in richness the illustrations in the treatises of al-Bīrūnī and al-Marrākushī, and the execution of the diagrams is certainly comparable in quality to the best manuscripts of, say, al-Bīrūnī's *Istīʿāb*.

Linguistic aspects of the text

Najm al-Dīn's treatise on instruments shares in general the linguistic peculiarities of the large majority of medieval scientific treatises written in Arabic in the Mamluk and Ottoman periods. Primarily it is written in Classical Arabic, but it shows substantial contaminations from Neo-Arabic (vernacular): this mixed language is commonly referred to as Middle Arabic.[151] The purpose of the present Section is to present an overview of the most unusual features.

A striking characteristic of the text is the systematic use of the dual form for a small plurality of objects or concepts (e.g., three). This, as far as I know, is not attested anywhere else and seems to be a fully idiosyncratic feature. In the edition I have corrected all occurrences of this 'pseudo-dual', noting the incorrect forms in the apparatus. Parallel to this phenomenon is the absence (with a few very rare exceptions) of authentic duals.

We also frequently encounter the use of the masculine plural pronoun *hum* and of the pronominal suffix (*-hum*) for inanimate objects, a standard Neo-Arabic feature. The Classical rules of grammatical accord are also constantly disregarded: we thus often find after a plural or feminine substantive the masculine singular relative pronoun *alladhī* or the personal pronoun *wa-huwa*. Likewise instead of the dual the feminine plural is often used: *li-l-burjayn al-madhkūra*; or the masculine singular: *hādhā al-rubʿayn* (both in Ch. 4). Also typical is the occurrence of *min mā* instead of its usual contraction *mimmā* (Ch. 33).

In one instance a curious construction is seen: Najm al-Dīn constantly calls the sundial whose standard name is *sāq al-jarāda*, "locust's leg" (see p. 3.2.1), *al-sāq jarāda*. This may be a case where the *status constructus* and the (indeterminate) *nomen rectum* have coalesced into a compound word (*sāq jarāda*), which can be rendered definite by the definite article.[152]

The particle of negation *mā* is occasionally employed before verbs in the imperfect, whereas in Classical Arabic it should only be followed by verbs in the perfect tense.

Several cases of emphatic assimilation occur (e.g. *s+ṭ→ṣṭ*): so the text has consistently *miṣṭara*, *aṣṭurlāb*, *uṣṭuwāna*, etc.). Such forms are very often

[150] See Hill 1979, Hill 1974 and Hill's chapter "Tecnología andalusí" in Samsó 1992, pp. 157–172 (English translation without illustrations in Hill 1998, item XVII), and the catalogue descriptions in *ibid.* pp. 298–308.

[151] Various essays dealing with Middle Arabic by the leading expert are collected in Blau 1988. A useful up-to-date introduction is Versteegh 1997, pp. 114–129.

[152] See Blau 1966, p. 350 (I owe this reference to Prof. Hans Daiber).

found in scientific manuscripts and have been left untouched in the edition. But we should note that copyist C3 of MS **D** wrote *asṭurlāb* always with a *sīn*.[153] There is one occurrence (in the caption of the illustration on **D**:23v) where copyist C2 also spelled this word in the same way.

The syntactical realisation of determinate ordinals occurs in four different forms, none of which corresponds to the classical rules. Thus, we have الثلاث مدارات (9 times), المدارات الثلاث (8 times), الثلاث المدارات (once), and المدارات الثلاثة (twice), whereas in Classical Arabic we would expect المدارات الثلاثة or ثلاثة المدارات.

The use of *khāṣṣatan*, "especially", in the sense of "only" is attested in several Middle Arabic texts.[154] Najm al-Dīn uses it frequently in this sense, e.g. in the expression *li-l-shams khāṣṣatan*, meaning "only for (timekeeping with) the sun".

More puzzling is the occurrence of بسطاطهم instead of بسطاتها "their landings [of stairs]" (Ch. 99): here we have three incorrect forms condensed in one word. First, the use of the pronominal suffix *-hum* for inanimate objects (here *daraj*, stairs); second, a feminine plural in *-āt* instead of the irregular plural *bisāṭ*; and third, the assimilation of the final *t* of the feminine plural suffix by the preceding *ṭ*. The copyist must have unconsciously written down this word as he pronounced it.

The use of the adjective مصطحي (always written مصطحب in **D**!) instead of سطحي "flat" is difficult to explain: it seems that the author invented a new morphological form of the model مفعلي.[155]

Najm al-Dīn's treatise contains three words that specifically belong to the Mamluk vocabulary, namely, *jūkān* (Ch. 77), *hanāb* (Ch. 23), and *bādahanj* (Ch. 91).[156]

A very interesting Middle Arabic variant of a classical word is *suḥlafa* or *zuḥlafa*, "tortoise", whereas the classical word for tortoise or turtle is *sulḥafā* (spelled سلحفى, سلحفاء or سلحفاة), but the "tortoise" astrolabe and quadrant featured in Chs. 21 and 47 are characterised either as *sḥlfī* (2 occurrences in **D**, 3 in **P**) or *zḥlfī* (!) (3 occurrences in **D**, 1 in **P**); at the end of Ch. 21 the rete (e.g. its zodiacal belt) is said to resemble a *zḥlfā* (زحلفاة); both spellings have thus an equal number of occurrences in the manuscripts (namely, 6).[157]

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[153] Since this is a foreign word both forms can be considered correct.

[154] See Blau 1988, pp. 339-343 (with references to Coptic-Arabic, Judæo-Arabic and Modern Arabic).

[155] This occurs in Chs. 59, 64, 76, 78, 87, 92, 94, 97, 98, 99, 106 and 109.

[156] On the first two words, see p. 256, n. 1, and p. 304, n. 1. On the latter, see King 1984.

[157] *Suḥlafā* seems to be a well-attested (semi-)vernacular form of *sulḥafā*: see Dozy, *Supplément* [quoting Bouctior, *Dictionnaire arabe-français*]. (It is semi-vernacular insofar as it does not pertain to the active spoken lexica: in Levantine Arabic the name for a tortoise is consistently *gurgaʿa*.) Apparently, the metathesis consisting in the permutation of an unvoweled liquid (such

1.5.4 *Editorial remarks*

Since the edition is based, for one half of the text, on two manuscripts, and for the other half on a single one, I have used the *sigla* **D** and **P** in the apparatus to identify the sources only for those parts which are based on two manuscripts. When the only source available is **D**, I have used the *siglum* **MS**, to make it clear that the edition relies on a single copy.

Square brackets are used for restorations of illegible portions of the text due to physical damage of the manuscript(s). Acute brackets indicate restorations of lacunæ in the text itself. Uncertain readings are indicated by (؟), unknown words or very uncertain readings by (؟؟) , and completely illegible words or passages by (؟؟؟) .

Legends of diagrams and text in diagrams are also edited and translated. The names of stars featured on retes are included in the edition but have been omitted in the translation. Instead, they are conveniently presented in a list in the second section of Appendix C.

Most 'incorrect' or colloquial forms have been left untouched, except the cases described in the previous Section; sometimes the form that would be expected in classical Arabic has been noted in a footnote. In a few cases, incorrect readings are marked by (!). On the other hand, *hamza*s have been fully restored according to Classical usage; they are almost never noted in the manuscripts (hence دائرة is written دايرة).

The copyist of **P** employed a *scriptio plena* for some words such as لاكن and ذالك . He also prefixed an *alif* to imperative forms in the second person singular of verbs having و as first root consonant (model *wʿl*), thus writing اضع instead of ضع .

In the translation I have attempted to render the elliptic and frequently confused original text into comprehensible modern English. It was necessary to insert a fairly large amount of explanatory additions between brackets: in all cases these have no counterpart in the Arabic text. Reconstructions of lacunæ

as l) and a following consonant is not uncommon in Neo-Arabic (or even in classical Arabic: cf. *maʾluka* < root *lʾk*; see *EI*[2], VIII, p. 532a). The further variant *zuḥlafā*, which is clearly attested in our manuscripts, might have arisen as a hypo-correction (or semi-correction; see Blau 1988, pp. 306–310) of *suḥlafā* by analogy with the authentically Arabic quadriliteral root *zḥlf* ("to roll along"), itself constructed from the triliteral root *zḥf* ("to advance slowly, to creep"), which is semantically appropriate for a tortoise. The word *zaḥālif* indeed means "reptiles, crawling insects with small feet like ants" (cf. the triliteral pendant *zawāḥif*: "creeping like reptiles").

My conjecture is that the classical quadriliteral word *sulḥafā* (of unknown foreign origin – see *EI*[2], IX, p. 811) would have undergone two transformations: (1) In post-classical Arabic it shifted to *suḥlafā* by metathesis; (2) through semantic analogy with the existing root *zḥlf* this then became *zuḥlafā* by sonorisation of the s. It seems probable that the original text had consistently the root *zḥlf*, and that the copyists, aware of its non-classical status, (unsystematically) made the semi-correction to *sḥlf*, hence unknowingly restoring the authentic postclassical version of a classical word.

and restorations of damaged text are noted with the same conventions as in the edition. Explanatory captions (such as 'remark', and 'text on the illustration'), which have no counterpart in the text, are included between acute brackets.

At the beginning of each chapter in the translation, a cross-reference to the corresponding pages of the commentary is given in the margin.

1.6 *Conventions used in the commentary*

The standard convention for denoting medieval trigonometric functions is to use upper case, which means their base is different than unity: sines and cosines are always to base 60, thus $\mathrm{Sin}\,\theta = 60\sin\theta$ and $\mathrm{Cos}\,\theta = 60\cos\theta$. The Cotangent and Tangent are always referred to as the horizontal and vertical shadow, and they assume that the shadow is cast by a gnomon of twelve digits in length; thus in this study the functions Cot and Tan will always be to base 12 (hence $\mathrm{Cot}\,\theta = 12\cot\theta$). The functions Vers and vers denote the versed sine, defined by $\mathrm{Vers}\,\theta = 60 - \mathrm{Cos}\,\theta$ (and $\mathrm{vers}\,\theta = 1 - \cos\theta$).

Sexagesimal numbers are denoted in the form $a;b,c$ introduced by Otto Neugebauer: the semicolon separates the decimal integer part from the sexagesimal fractions, which are separated by commas. In Najm al-Dīn's treatise, as in most Islamic astronomical works, numbers are either written in words or with alphabetical notation.

The mathematical symbols used in the commentary are collected in the following list.

- a azimuth (*al-samt*), counted clockwise from the east
- B 'base' (*al-aṣl*), a very frequent auxiliary function used in Islamic spherical astronomy from *ca*. 1200 onward
- d equation of daylight (*niṣf faḍl al-nahār*):
  $d(\phi,\delta) = \arcsin(\tan\phi\ \tan\delta)$.
  (In the context of gnomonics d denotes the declination (*inḥirāf*) of a sundial, defined by Najm al-Dīn as the angle made between its southernmost extremity and the meridian line.)
- D half arc of visibility (*niṣf al-qaws*); the duration of half daylight (*niṣf qaws al-nahār*) is the half arc of visibility of the sun:
  $D = 90^\circ \pm d$.
  (In the context of gnomonics D denotes the declination of a sundial according to the *modern* definition: see p. 184.)

g	length of a gnomon (usually measuring 12 digits)
g'	On inclined sundials g' is the length of a horizontal gnomon
h	instantaneous altitude (*al-irtifāʿ*)
h_i^s	solar altitude at the i^{th} seasonal hour
h_i^e	solar altitude at the i^{th} equal hour
h_0	altitude in the prime vertical (*al-irtifāʿ alladhī lā samt lahu*)
h_a	solar altitude at the time of the beginning of the afternoon prayer (*irtifāʿ awwal al-ʿaṣr*). The afternoon prayer begins when the shadow of a vertical gnomon has increased over its length at midday by an amount equal to the length of the gnomon.
h_b	solar altitude at the time of the end of the afternoon prayer (*irtifāʿ ākhar al-ʿaṣr*). The afternoon prayer ends when the shadow of a vertical gnomon has increased over its its length at midday by an amount equal to twice the length of the gnomon.
h_q	solar altitude when its azimuth coincides with the azimuth of Mecca
h_m	meridian altitude (*al-ghāya*): $h_m = 90° - \phi + \delta$ (or $90° + \phi - \delta$ when $\phi < \delta$)
i	inclination of a sundial with respect to a vertical surface
I	inclination of a sundial according to the *modern* definition, with $I = 90° - i$ (see p. 184).
R	the trigonometric base: $R = 60$ (unless otherwise stated)
R_E	The radius of the equatorial circle on astrolabic plates
t	hour-angle (*faḍl al-dāʾir*): $t = D - T$
T	time-arc (*dāʾir*), i.e., the time in equatorial degrees elapsed since rising or remaining until setting (the accurate formula is given on p. 216)
u	horizontal shadow: $u = \text{Cot}\,h = g\cot h$
v	vertical shadow $u = \text{Tan}\,h = g\tan h$
u_m	horizontal shadow at midday: $u_m = \text{Cot}\,h_m = g\cot h_m$
v_m	vertical shadow at midday: $v_m = \text{Tan}\,h_m = g\tan h_m$
x, y	Cartesian coordinates on quadrants and portable dials
α	normed right ascension, measured clockwise from the first point of Capricorn (for the sun we have $\cos\alpha = \tan\delta/\tan\varepsilon$.)
α'	distance in right ascension from the nearest equinox, measured clockwise
β	latitude of a star (*ʿarḍ al-kawkab*)
δ	declination of the sun (*mayl al-shams*):

	$\delta(\lambda) = \arcsin(\sin\varepsilon \sin\lambda)$
Δ	declination of a star (*buʿd al-kawkab*)
ε	obliquity of the ecliptic (*al-mayl al-aʿẓam*), which Najm al-Dīn assumes to be 23;35°, a value attested from the ninth century onward
λ	longitude of the sun (*darajat al-shams*) or of a star (*ṭūl al-kawkab*)
λ'	distance in longitude from the nearest equinox, measured clockwise
ρ	the distance from the origin in a polar coordinate system
θ	the angle in a polar coordinate system
ϕ	latitude of a locality (*ʿarḍ al-balad*)
ψ	rising or setting amplitude (*saʿat al-mashriq* or *saʿat al-maghrib*): $\psi = \arcsin(\sin\delta / \cos\phi)$
ξ, η	Cartesian coordinates on fixed sundials
$\_^*$	The asterisk refers to the opposite point of the ecliptic, thus: $\lambda^* = \lambda + 180°$ and $f^*(\lambda) = f(\lambda + 180°)$.

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Part II

COMMENTARY

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CHAPTER TWO

ASTROLABES AND RELATED INSTRUMENTS

It is only natural that an exhaustive survey of medieval instruments would begin with the astrolabe, which, on account of its antiquity, ingenuity and beauty was justifiably considered the noblest of all mathematical instruments. This chapter deals more generally with all instruments that depend upon stereographic projection.[1] The different categories of astrolabes treated by Najm al-Dīn are here presented according to my own classification based on morphological and historical criteria. I shall thus begin with the standard planispheric astrolabe, and then deal with the spherical and linear ones, all possible variants of the planispheric astrolabe for a single latitude, astrolabic quadrants, instruments based on stereographic projections on the horizon and finally astrolabes based on universal projections.

2.1 *The standard planispheric astrolabe*

The general history of the standard astrolabe is well documented, so attention is restricted here to unusual features of Najm al-Dīn's presentation.[2]

A note on Najm al-Dīn's astrolabe terminology. Najm al-Dīn's terminology for designating the different parts of the astrolabe is standard.[3] Worthy of notice are the terms employed for the diameters and radii on each astrolabic

[1] The spherical astrolabe is also included because historically it was derived from the planispheric astrolabe.

[2] On the history of the astrolabe, see Neugebauer 1949; Neugebauer 1975, pp. 868–879; Drachmann 1954; Frank 1920; Kunitzsch 1981; Kunitzsch 1982, pp. 7–11. On its construction and use, see Hartner 1938-39; Michel 1976; North 1974. The tradition of Ptolemy's *Planisphærium* and related theoretical discussions of stereographic projection are presented in Neugebauer 1975, pp. 857–868; Anagnostakis 1984; Kunitzsch & Lorch 1994; Sergeyeva & Karpova 1978; Lorch 1996; Lorch 2000b. Geometrical methods for constructing astrolabes are analysed in Berggren 1991; Anagnostakis 1987; Michel 1941. Numerical methods are investigated in King 1983b, pp. 23–27; King & Charette, "Astrolabe Tables". The Arabic terminology of the medieval European astrolabe literature is surveyed in Kunitzsch 1982 and idem 1984. On Muslim additions to the standard astrolabe, see King 1996c. Contextual studies on the astrolabe and its multiple functions as a didactical tool or as a prestige object, or about its symbolism or iconography, are non-existent.

[3] There exists no study of the Arabic astrolabe terminology comparable to Kunitzsch 1982 (dealing with the European tradition, which is derived from the Arabic one).

plate: The vertical diameter is called *khaṭṭ niṣf al-nahār*, "meridian line" or alternatively *khaṭṭ al-zawāl*, "midday line".[4] Its upper half is designated *khaṭṭ al-ʿilāqa*, 'line of the suspensory apparatus' (this line indeed extends from the *ʿilāqa* to the centre of the plate).[5] The lower half of the vertical diameter is called *khaṭṭ watad al-arḍ*, "line of the pivot of the earth", which occurs in this form only once (Ch. 7): everywhere else the abbreviation *khaṭṭ al-watad*, "line of the pivot", is preferred.[6] The origin of this denomination – which goes back to the eighth century – is astrological, the "pivot of the earth" being the intersection of the ecliptic with the invisible half of the meridian, which defines the limit between the third and fourth astrological houses.[7] Since this line goes from the central hole, in which the peg (*watad*, also called *miḥwar*, "axis") is inserted, to the lowest extremity of the plate, Najm al-Dīn or some of his predecessors probably interpreted the term *watad* in a concrete sense, and coined the corresponding designation *khaṭṭ al-ʿilāqa* in analogy to it. The horizontal diameter is called *khaṭṭ al-mashriq wa-l-maghrib*, "east-west line"; its left- and right-hand halves are called *khaṭṭ al-mashriq* and *khaṭṭ al-maghrib*.[8]

The east and west points (i.e., the intersections of the east-west line with the equator) are sometimes referred to as *quṭbay al-tasṭīḥ*, "the two poles of projection": this terminology results from imagining the meridian circle on the sphere to be folded on the plane about its north-south axis, so that the northern or southern pole coincides with the east or west point of the plate; from these 'poles' it is possible to geometrically construct quantities related

[4] The Latin texts on the astrolabe use a Latinised form of the term *khaṭṭ al-zawāl* to designate the *lower* half of the vertical diameter (no doubt because the sixth hour-line coincides with it – see Section 2.1.3); see Kunitzsch 1982, no. 14. This simply reflects the terminology used by the Western Islamic texts on which the Latin tradition is based; Ibn al-Samḥ, for example, gives this term as as an alternative designation, next to the more usual expressions listed below: see Viladrich 1986, p. 105. This, however, was not the standard definition encountered in Arabic astrolabe texts: as far as I can attest, this term is used in Eastern Islamic sources for designating either the whole meridian line (as for example al-Khwārizmī: see Charette & Schmidl, "Khwārizmī".) or, in the context of quadrants, its upper half.

[5] This idiosyncratic term is used on nine occasions in the treatise.

[6] This term also occurs frequently in the context of vertical or inclined sundials. See the remarks on p. 4.3.

[7] The counterpart of this term is *khaṭṭ wasaṭ al-samāʾ* "line of mid-heaven", the 'midheaven' being the intersection of the ecliptic with the meridian, the limit between the ninth and tenth houses. Both terms occur in the astrolabe treatises of ʿAlī ibn ʿĪsā and al-Khwārizmī (on the former see p. 60, n. 33 below, and on the latter see Cheikho 1913, p. 35 and Charette & Schmidl, "Khwārizmī").

[8] The above terminology is found in most of the astrolabe literature, with the exception of the term *khaṭṭ al-ʿilāqa*, as this line is in general called *khaṭṭ wasaṭ al-samāʾ*: see for example al-Bīrūnī, *Tafhīm*, illustration facing p. 195b and § 326 of the translation (note that the corresponding passage of the manuscript reproduced in facsimile in that book is defective), and again al-Bīrūnī, *Istīʿāb*, MS Leiden UB Or. 591, p. 57:9-12. In the *Tafhīm* we also find *khaṭṭ niṣf al-layl*, "line of midnight" as an alternative for *khaṭṭ watad al-arḍ*. Abū al-Ṣalt (MS London BL Or. 5479, Ch. 1 – cf. al-Marrākushī, *Jāmiʿ*, II, p. 41:1-2) calls the horizontal diameter *khaṭṭ al-istiwāʾ*, "equatorial line", and *khaṭṭ ufuq al-istiwāʾ*, "line of the equatorial horizon".

to stereographic projection.

The rete is designated throughout as *al-shabaka*, “the net”, and the synonymous *al-ʿankabūt*, “the spider”, is never used.

2.1.1 *Najm al-Dīn’s numerical method for constructing astrolabe markings*

The last chapter of Part 1, containing Najm al-Dīn’s exhaustive set of instructions on the use of his universal auxiliary tables, should logically belong to Part 2. Its purpose is to present a method for finding by calculation the radii of the various circles that are represented on a standard astrolabic plate, which is of fundamental importance for constructing astrolabic instruments. Najm al-Dīn’s method, which is referred to twice in the first chapter of Part 2 as “the procedure presented in the last of the chapters [of Part 1]”, is equivalent to the standard trigonometric formulæ of stereographic projection, but it involves some arithmetical tricks to make the computation easier. The procedure is indeed applied numerically in Ch. 5, but only for constructing the horizon.[9]

The procedure can be summarised as follows. We assume a diameter of 60 units for the plate, whose circumference coincides on a northern astrolabe with the projection of the tropic of Capricorn. The nearest and farthest distances from the centre of the plate of an altitude circle for argument h will be given by

$$d_{\max}(\phi,h) = R_E \cot\left(\frac{\phi+h}{2}\right) \quad \text{and} \quad d_{\min}(\phi,h) = R_E \tan\left(\frac{\phi-h}{2}\right),$$

respectively, where R_E is the radius of the equator. If $\phi+h > 90°$, then take $180° - (\phi+h)$ instead. To find the radius $r(\phi,h)$ of an altitude circle, add the above quantities, add to their sum two thirds of it (i.e., take five thirds of the sum), and finally “subtract one minute from each degree of the result” (i.e., take $\frac{59}{60}$ thereof). In modern symbolism,

$$\begin{aligned} \text{let} \quad & x = d_{\max}(\phi,h) + d_{\min}(\phi,h) \\ \text{and} \quad & y = x + \tfrac{2}{3}x = \tfrac{5}{3}x, \\ \text{then} \quad & r = y - y/60 = \tfrac{59}{60}\,\tfrac{5}{3}\,x. \end{aligned}$$

The radius is thus expressed as:

$$\begin{aligned} r(\phi,h) &= \frac{59}{60}\,\frac{5}{3}\left\{\mathrm{Cot}\left(\frac{\phi+h}{2}\right) + \mathrm{Tan}\left(\frac{\phi-h}{2}\right)\right\} \\ &= \frac{59}{3}\left\{\cot\left(\frac{\phi+h}{2}\right) + \tan\left(\frac{\phi-h}{2}\right)\right\}. \end{aligned}$$

[9] A similar procedure is also mentioned in Ch. 39 for finding the radii of the declination circles on a universal astrolabe. See Section 2.6 below.

We recognise in the last equation the expression for radius of an altitude circle in stereographic projection, with the radius of the equator R_E taken as $\frac{59}{3} = 19;40$. The exact value of that parameter, assuming a radius of the plate $R = 30$ and an obliquity $\varepsilon = 23;35°$, should be $60\ \cot(45° + \varepsilon/2) = 19;38$. The value $19;40$, however, corresponds exactly to a calculation based on Najm al-Dīn's Cotangent table with values given to the minutes for each minute of argument, thus:[10]

$$\tfrac{30}{12}\ \mathrm{Cot}\,\tfrac{90°+23;35°}{2} = \tfrac{30}{12}\ \mathrm{Cot}\,56;47,30° = \tfrac{30}{12}\ 7;52 = 19;40,$$

where 7;52 is the entry for Cot$56;47°$ and for Cot$56;48°$ in Najm al-Dīn's Cotangent table (**B**:171r). Curiously, elsewhere in Part 2 (see Chs. 1, 15, 40, 42 and 43) the radius of the equator is given as $19;39^p$, which is the parameter found in al-Farghānī's treatise on the construction of the astrolabe,[11] and reproduced by al-Marrākushī.[12] But the numerical values he gives for radii of projection agree better with his approximation of 19;39 through the fraction $\frac{59}{3}$ (see the excursus below).

Najm al-Dīn adds that it is possible to tabulate $r(\phi,h)$ for the desired range of the argument h in order to construct the altitude circles. In practice he used another method, which I shall explain in Section 2.1.2 below. The procedure for finding the projection of the prime vertical is similar, and its radius r_0 is given by:

$$\begin{aligned} r_0(\phi) &= \tfrac{1}{2}\left\{d_{\max}(\phi) + d_{\min}(\phi)\right\}, \\ \text{with} \quad d_{\max}(\phi) &= \tfrac{5}{3}\ \tfrac{59}{60}\ \mathrm{Tan}\left(\frac{90+\phi}{2}\right) \\ \text{and} \quad d_{\min}(\phi) &= \tfrac{5}{3}\ \tfrac{59}{60}\ \mathrm{Tan}\left(\frac{90-\phi}{2}\right).^{13} \end{aligned}$$

Najm al-Dīn finally presents the following equivalent formula:

$$r_0(\phi) = \tfrac{5}{3}\ \tfrac{59}{60}\ \{\mathrm{Tan}\,\bar{\phi}/2 + \mathrm{Cot}\,\bar{\phi}/2\},$$

where the argument $\bar{\phi}$ is called the "meridian altitude of Aries". The above expressions are both equivalent to the simpler modern formula $r_0(\phi) = R_E \sec\phi$.

Excursus: Analysis of the numerical parameters associated with stereographic projection

In Ch. 1, as well as in Chs. 5, 6, 7 and 15, Najm al-Dīn provides the reader with the numerical parameters for the radii of projection of basic circles. The

[10] The Cotangent table is found in **B**:167r–173v; see Charette 1998, p. 21.

[11] See King & Charette, "Astrolabe Tables".

[12] al-Marrākushī, *Jāmiʿ*, I, p. 178; Sédillot, *Traité*, p. 348.

[13] The text gives erroneously $\frac{90+\bar{\phi}}{2}$ as the argument of the Tan function in the expression for $d_{\max}$.

diameter of the outer tropic (Capricorn on northern astrolabes) is assumed to measure 60 units. The radii of the following declination circles are given in Ch. 1: equator: 19;39, Cancer: 12;54, Taurus: 15;30, Gemini: 13;42. The distance of the zenith from the centre (for latitude 36°) is also given as 10;2. The passage concerning a star with declination 30° gives the quantities 8;46 and 11;46 as farthest and nearest distances from the 'pole', which makes no sense. Both quantities are obviously corrupt. In Chs. 5, 6, 7 and 15 the nearest and farthest distances from the centre of the intersections of the horizon circle (of latitude 36°) with the meridian are given as 6;24 and 60;32.

Let us now recompute these values using Najm al-Dīn's Cotangent table and assuming the approximation $59/3$ for the radius of the equator:

For Cancer we find $59/3\tan(\frac{90-23;35}{2}) = \frac{59}{36}\ \mathrm{Cot}\,56;47,30^\circ = \frac{59}{36}\ 7;52 = 12;54$.[14] For Taurus we have $\delta(30^\circ) = 11;32$, so that $59/3\tan(\frac{90-11;32}{2}) = \frac{59}{36}\ \mathrm{Cot}\,50;46^\circ = \frac{59}{36}\ 9;47 = 16;2$, which means that the value given by Najm al-Dīn, 15;30, is incorrect. This error can be explained by assuming that the adjacent entry for $\mathrm{Cot}\,51;46 = 9;27$ has been taken instead, since this yields 15;29. For Gemini we have $\delta(60^\circ) = 20;16$, so that $59/3\tan(\frac{90-20;16}{2}) = \frac{59}{36}\ \mathrm{Cot}\,55;8^\circ = \frac{59}{36}\ 8;22 = 13;43$.[15]

The distance zenith–centre is given by $59/3\tan(\frac{90-36}{2}) = \frac{59}{36}\ \mathrm{Cot}\,63^\circ = \frac{59}{36}\ 6;7 = 10;01,29$. The nearest distance of the horizon is $59/3\tan(\frac{90-54}{2}) = \frac{59}{36}\ \mathrm{Cot}\,72^\circ = \frac{59}{36}\ 3;54 = 6;23,30$. The farthest distance of the horizon is $59/3\tan(\frac{90+54}{2}) = \frac{59}{36}\ \mathrm{Cot}\,18^\circ = \frac{59}{36}\ 36;56 = 60;32$.

Thus, the way in which the above parameters were computed can be confirmed.

2.1.2 *A practical method for constructing astrolabic plates by means of timekeeping tables*

The general method proposed by Najm al-Dīn for constructing the markings on astrolabe plates is unique in the medieval literature. Yet the idea is ingenious and quite simple. Instead of considering the centres and radii of the altitude or azimuth circles, one can also construct each of these circles by knowing three points of its circumference, or two points as well as a line passing through its centre.[16] The positions of such points can be easily found from the data contained in a timekeeping table compiled for a specific latitude. For altitude circles, the hour-angle $t(h,\delta)$ is tabulated for up to three appropriate values of the declination δ, and for a range of altitudes h (here for each 6°). The declination arguments are chosen so that the corresponding

[14] With $R_E = 19;39$ the result would be 12;53.

[15] With $R_E = 19;39$ the result would be 13;42.

[16] The equivalent problem of finding a circle circumscribing a given triangle is explained in Euclid's *Elements*, IV.5. See Heath 1956, II, pp. 88–90.

declination circles intersect the altitude circles on the astrolabic plate. The hour-angle $t(h,\delta)$ can be obtained from Najm al-Dīn's *Tables of Time-arc* according to the instructions in Ch. 21.[17] One puts the ruler at the centre of the plate and, on the outer scale on each side of the meridian, upon the value of the hour-angle tabulated for different declination circles. Marking the intersections of the ruler with the appropriate declination circle will yield two or three points of the circumference of the altitude circle h (see Fig. 2.1). Putting one leg of the compass on the meridian line, successive approximations give a centre and an opening with which it is possible to join those points with a circular arc. An exact geometrical construction of the centre is of course possible, but in practice the not-so-elegant procedure just described is quicker and provides satisfying results.

For the azimuth circles, the hour-angle $t(a)$ at the equinox is tabulated for a range of azimuths (here for each 10° – see the bottom right section of Table T.1). These angular values should first be marked on the circumference of the equatorial circle, as shown in Figure 2.2. Then the prime vertical is drawn as the circle passing through the zenith and the east and west points. The nadir will be its lower intersection with the meridian. The horizontal diameter of this circle is then traced and extended "indefinitely" (!) on both sides, as in the geometrical procedure which al-Bīrūnī calls the "procedure which is widely known among the practitioners" (*al-ʿamal al-mashhūr … bayna ahl al-ṣināʿa*).[18] It is an established property of stereographic projection that the centres of the azimuth circles are located on that line.[19] This makes it possible to determine the azimuth circles, since for each of them two points of its circumference (namely, the zenith and one of the azimuth circle's intersections with the equatorial circle), as well as the line on which its centre is located, are known. It is then a simple matter to find this centre by successive approximations with the compass.

Najm al-Dīn repeats the same explanations of the construction of azimuth circles in Chs. 31 and 50; the former is devoted to a plate bearing only azimuth circles, which should be included among the plates of astrolabes featuring mixed projections (see Section 2.3.3), since the markings on the plates of such astrolabes would become too intricate if they were to include azimuths. Ch. 50 features the "azimuthal quadrant", which consists in the same mark-

[17] The hour-angle t being found from $t(H,h,D) = D(\phi,\lambda) - T(H,h,D)$.

[18] al-Bīrūnī, *Istīʿāb*, MS Leiden UB Or. 591, p. 90. This method of drawing azimuth circles and variants thereof is presented by al-Sijzī, al-Bīrūnī, al-Marrākushī and others. See Berggren 1991, pp. 330–336.

[19] A proof of this property is presented by al-Kūhī; see Berggren 1991, pp. 324–327, and idem 1994, pp. 156–160 (translation) and pp. 239–244 [= A9–A14] (text). Berggren (p. 331), states that al-Sijzī uses this result of Kūhī's without quoting or proving it. In fact, al-Sijzī *did* present his own proof of this in the tenth proposition of the first part of his astrolabe treatise (MS Istanbul Topkapı Ahmet III 3342, ff. 128v–129v).

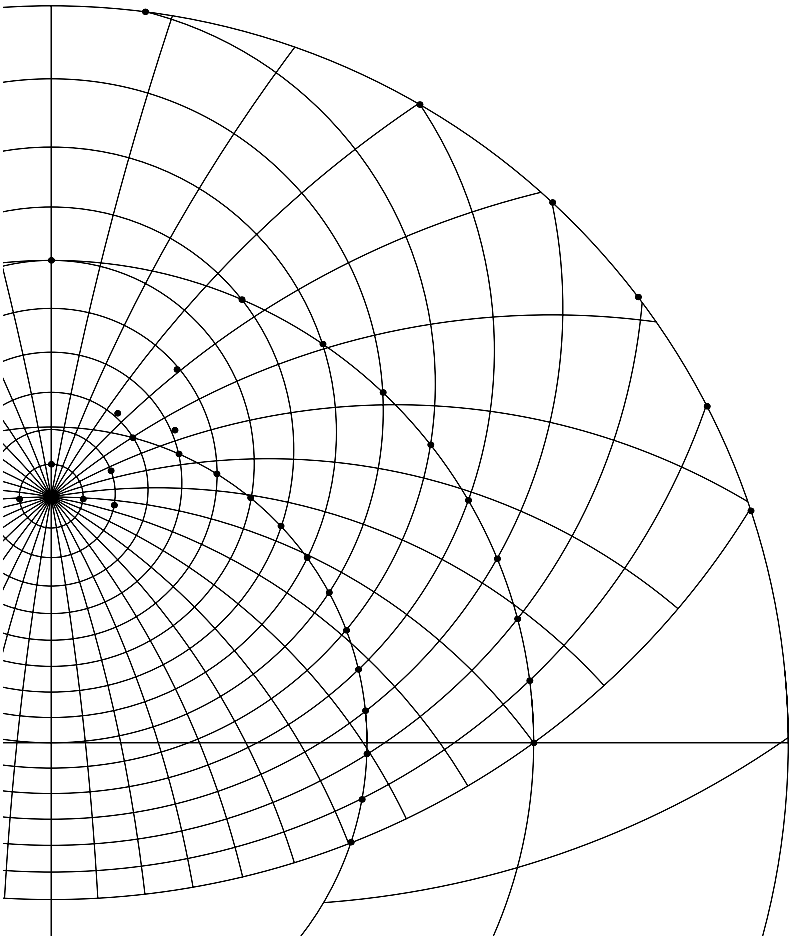

FIG. 2.1. Representation of the entries of Table T.1 for constructing the altitude circles (note that the three entries for Taurus and Gemini are clearly in error)

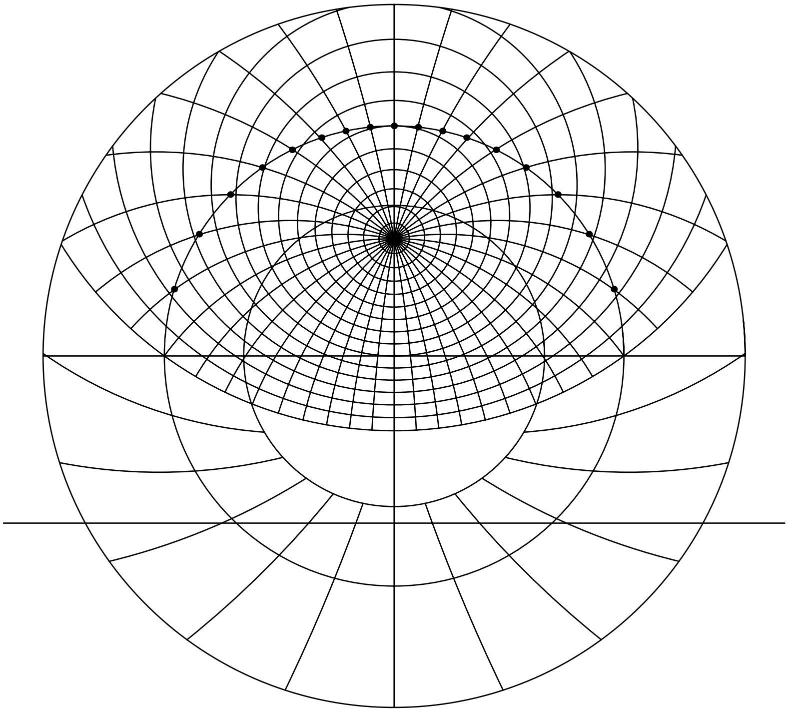

FIG. 2.2. Representation of the entries of Table T.1 for constructing the azimuth circles

ings on the back of non-standard astrolabic quadrants (see Section 2.4.1). But the procedure described in these two chapters is erroneous, as Najm al-Dīn suggests putting the marks corresponding to the time-arc of the azimuth arguments on the outer circle of the plate (or on the arc of the quadrant) instead of the equatorial circle.

With Najm al-Dīn, the construction of astrolabic plates has left the domain of applied geometry and has attained the level of 'tricks' for practitioners of *ʿilm al-mīqāt* and instrument-making. His method might seem cumbersome at the first sight, but in fact it does work quite well in practice. Yet the standard numerical and geometrical procedures remain superior to his and are more reliable.

An illustration of the plate and rete of a standard northern astrolabe in Ch. 1 of Najm al-Dīn's treatise is provided in Plate 1.

The southern astrolabe

The southern astrolabe – which results from a stereographic projection with respect to the northern celestial pole – is briefly treated in Ch. 2. Its construction does not present any difficulty, as Najm al-Dīn himself tells his reader, and the table included in Ch. 1 provides all the necessary data for tracing its altitude and azimuth circles.[20] One detail worthy of mention concerning the construction of azimuth circles is omitted by Najm al-Dīn, namely, that the line parallel to the east-west line on which the centres of all azimuth circles are located will now be in the upper half of the plate, and that it is necessary to mark the nadir on the plate (below the horizon) in order to trace the azimuth circles properly.

The construction of retes

The geometric construction of the ecliptic ring on the rete is trivial. The division of the scale involves a table of right ascensions. The position of a star-pointer is determined by means of the right ascension of the associated star and its radius, which is found by placing one leg of the compass at the centre of the plate and the other one upon the altitude circle on the meridian corresponding to the meridian altitude of this star. The equatorial coordinates of 349 different stars are given in a table which Najm al-Dīn included in the corpus of tables accompanying his universal auxiliary tables.[21] This table, on which the names and positions of the star-pointers of all illustrations of retes in manuscripts **P** and **D** are based, is edited in Appendix C, together with a detailed analysis of those illustrations.

2.1.3 *Special plates and optional markings*

Azimuthal plate

A special plate provided exclusively with azimuth markings is presented in Ch. 31, in order to compensate for the absence of such markings on most astrolabic plates involving mixed projections (see Section 2.3.3). Curiously, this plate is called the "azimuthal circle" (*al-dāʾira al-samtiyya*). There is also a corresponding quadrant, described in Ch. 50 (*al-rubʿ al-samtī*).

Hour curves on astrolabe plates

Already on the anaphoric clock – one of the earliest instruments to apply the principle of stereographic projection – we find a representation of the lines delimiting the 24 seasonal hours of day and night.[22] In its earliest form, the

[20] The entries for declinations 30° and 36° are, however, of no use here, since they are outside the range of a southern plate.
[21] See Charette 1998, p. 21 and above p. 25 (item 3).
[22] On this instrument, see Drachmann 1954 and A. Turner 2000.

astrolabe also featured markings for the seasonal hours on each plate, but instead of including all 24 hour-lines as on the anaphoric clock, it only displayed the twelve hours of night under the horizon, beginning from the western horizon.[23] The reason for this restriction is simply that if the diurnal hour-lines were represented, they would intermingle with the altitude circles,[24] with unfortunate practical and æsthetical consequences.[25] When using the astrolabe at night, the position of the degree of the ecliptic below the horizon – resulting from setting a star-pointer over the altitude circle corresponding to the measured altitude of the corresponding star – will readily indicate the time of night in seasonal hours. In order to use the astrolabe during the day, one has to be aware of the following symmetry property of the celestial sphere: if a point of the ecliptic with longitude λ intersects the circle of altitude h, then its opposite point $\lambda^* = \lambda + 180°$ will intersect the circle of altitude $-h$ below the horizon. This has the consequence that the time of night in seasonal hours corresponding to the position of the 'anti-sun' under the horizon will be the same as the time of day indicated by the sun over the horizon. The time of day can thus be determined by considering the position of the opposite degree of the ecliptic with respect to the nocturnal hour-lines.

Constructing these hour-lines is a simple task: the portion below the horizon of each three day-circles should be divided into twelve equal parts, and each three division should be connected by a circular arc. Najm al-Dīn's instructions are either incomplete (Ch. 1) or too complicated (Chs. 51 and 52). The method presented in Chs. 51 and 52 implies using a table of h_i^s or h_i^e; this is an absurd idea, but it follows the 'logic' adopted by our author elsewhere (cf. Ch. 103). Although the procedure underlying these two chapters is not fundamentally wrong, the precise instructions given in the text are so garbled as to make little sense.

Prayer curves

Curves indicating the times of prayers were probably introduced on astrolabe plates in the tenth century. They do not occur in any astrolabe treatise from the ninth or early tenth centuries, but are mentioned (for the first time, as far as I know) in al-Bīrūnī's *Istīʿāb* (*ca.* 1000 AD). The latter describes markings for the evening and morning twilights, represented as altitude circles below the horizon by $-17°$ or $-18°$, depending on the authors.[26] He then describes

23 See Neugebauer 1949, p. 243 and Stautz 1993.

24 The earliest astrolabes did not yet feature azimuth circles, which were an innovation of Muslim instrument-makers *ca.* 200 H [= 815/6].

25 al-Bīrūnī, however, mentions that some people made the equal hours since sunrise either above the horizon or below it, but that they were drawn as dashed curves in order not to confuse them with either the altitude circles or the seasonal hour-lines: see al-Bīrūnī, *Istīʿāb*, MS Leiden UB Or. 591, p. 79:16-20. Several Iranian astrolabes with dashed curves for the equal hours are known, but on all of them the hour-lines are below the horizon.

26 al-Bīrūnī, *Istīʿāb*, MS Leiden UB Or. 591, p. 87:1-10.

the construction of curves for the beginning and end of the afternoon prayer (*ʿaṣr*).[27] Such curves are found on virtually all Maghribi astrolabes from the eleventh to the eighteenth century, but they were very rare in the East.

These curves are constructed as follows, assuming a table of $h_a(\lambda')$ and $h_b(\lambda')$: for each argument λ' of the table one lays the corresponding ecliptic degree on the altitude circle corresponding to h_a or h_b, in the western side, and makes a mark in the lower left quadrant of the plate vis-à-vis the opposite degree $\lambda' + 180°$ of the ecliptic belt. The curve can be traced by joining the construction marks as a regular curve.[28] al-Bīrūnī also mentions the possibility of shortening the operation by approximating the curves through circular arcs connecting three points marked on the basic day-circles.[29] This approximation is valid only for latitudes greater than the obliquity. Although Najm al-Dīn never mentions prayer curves in his general discussion of astrolabe plates, he does devote a complete chapter to the drawing of *ʿaṣr* curves on astrolabe plates and horizontal sundials when $\phi < \varepsilon$, a special case which his predecessors al-Bīrūnī and al-Marrākushī had omitted to discuss. I consider this in the context of plane sundials (see Section 3.5.2). Moreover, the topic of representing the *ʿaṣr* on quadrants and dials will be dealt with in Section 3.5.

Plate of horizons

The plate of horizons (*al-ṣafīḥa al-āfāqiyya*) consists of four families of half-horizons for a extensive range of latitudes, evenly distributed over the four quadrants of a circular plate; it is completed by declination scales along the radii. Its invention goes back to ninth-century Baghdad, but the precise circumstances are not known. The Andalusī author Abū 'l-Qāsim al-Zubayr ibn Aḥmad ibn Ibrāhīm ibn al-Zubayr[30] reports the following:

> Among the different kinds of planispheric astrolabes, one is called the *āfāqī*. I think that it is the one which is attributed to Ḥabash – may God have Mercy upon him. It is called thus because it comprises the straight and oblique horizons.[31]

This description seems indeed to refer to the plate of horizons, which is not an astrolabe on its own, as al-Zubayr implies, but was commonly engraved on one side of the plates of Eastern Islamic astrolabes made from *ca*. 900 AD

[27] *Ibid.*, pp. 87:10–88:3. For the definition of the *ʿaṣr* prayer see p. 44.

[28] This procedure is also explained in al-Bīrūnī, *Shadows*, pp. 233–234.

[29] *Ibid.*, p. 234.

[30] Son of the traditionist Ibn al-Zubayr (627–708 H/1230–1308); see *EI*², III, p. 976.

[31] Quoted in Morley 1856, p. 7, n. 12 [where "Ḥanash" should read "Ḥabash"], from Ibn al-Zubayr's work on the astrolabe entitled *Tadhkirat dhawī 'l-albāb fī stīfāʾ al-ʿamal bi-l-asṭurlāb*: see Suter, *MAA*, no. 513, Brockelmann, *GAL*, SII, p. 1025, King, *Fihris*, II, pp. 403–404, and King, *Survey*, no. F21.

onward.[32] In a treatise on its use by ʿAlī ibn ʿĪsā (*fl.* 217–231 H [= 832–846][33] it is described, however, as an independent instrument, with the horizons on one side of a plate and trigonometric markings on the other side.

This plate is a useful but restricted universal device, which was conceived to solve astronomical problems related to the horizon. The early treatises on its use are, however, unpublished and have never been studied.[34] In passing we note that the representation of a whole set of horizons inside the equatorial circle is identical to the representation of the meridians on the universal projection; yet nothing suggests that anyone in the Eastern Islamic world would have anticipated the invention of the eleventh-century astronomers of al-Andalus, ʿAlī ibn Khalaf and Ibn al-Zarqālluh (see Section 2.6).

Construction. The method proposed by Najm al-Dīn for constructing the arcs of horizons (Ch. 26) makes use of tabulated values of the half-excess of daylight at each 10° of latitude. Underlying this is undoubtedly the observation that the arc defined by the distance from the east or west point to the intersection of the horizon circle with the circle of Capricorn corresponds to the maximum half-excess of daylight. A very simple and expeditive way to trace any horizon would be to mark that quantity on the circle of Capricorn on the eastern and western sides, and to draw – by successive approximations – a circular arc centred on the meridian line which passes through these markings and through the east and west points of the equator. This method corresponds to the 'easier' alternative proposed by Najm al-Dīn at the end of Ch. 26. However, the main method outlined in this chapter is erroneous.

Najm al-Dīn tells his reader to put a ruler at the centre and on the circle of Capricorn upon the values of the maximal half-excess of daylight, and to put marks at the intersection of the ruler with the *equatorial* circle. (These marks should be put successively in each quadrant in a clockwise order, in

[32] The earliest extant astrolabe featuring a plate of horizons was made by Ḥāmid ibn ʿAlī in 343 H [= 954/5] (formerly in Palermo, now lost: described and illustrated in Mortillaro 1848), where he horizons are engraved on the mater, albeit in a problematic manner. The second one is featured on one of the plates of the celebrated astrolabe of al-Khujandī, dated 374 H [= 984/5]: see King 1995, p. 87.

[33] According to al-Masʿūdī (*Murūj*, VIII, p. 291), ʿAlī would have been active at the times of al-Manṣūr (d. 158 H [= 775]), but this seems hardly reconcilable with his conducting observations as late as 231 H [= 845/6]. Ibn al-Nadīm's (*Fihrist*, p. 342) mention that he was a pupil of al-Marwarrūdhī also seems to contradict the latter statement.

[34] If he really is the inventor of the *ṣafīḥa āfāqiyya* then Ḥabash should have composed a treatise on its use, which is lost. The earliest extant sources on the plate of horizons include: (1) ʿAlī ibn ʿĪsā, fragments on *al-Ṣafīḥa al-āfāqiyya* in MS London BL Or. 5479/4 (other copies might be available: see Sezgin, *GAS*, VI, p. 144, note); (2) Anon. (probably datable *ca.* 900 AD), *Risālat al-ʿAmal bi-l-ṣafīḥa al-āfāqiyya*, in 64 chapters, MS Oxford Bodleian Marsh 663, pp. 115–126 – (*faṣl* 1, *fī 'l-Aʿmāl al-nahāriyya*, in 46 *bāb*s and *faṣl* 2, *fī 'l-Aʿmāl al-layliyya*, in 18 *bāb*s); (3) al-Sijzī, *Kitāb al-ʿAmal bi-l-ṣafīḥa al-āfāqiyya*, in 120 chapters, MS Damascus Ẓāhiriyya 9255; (4) A section of al-Bīrūnī's *Istīʿāb*: see al-Bīrūnī, *Istīʿāb*, MS Leiden UB Or. 591, pp. 82–84.

such a way that the half-horizons be evenly distributed around the plate, but Najm al-Dīn does not explain this.) Next, one places the ruler upon the east or west point of the horizon (called "poles of projection") and upon each mark made on the equator, and one makes a new mark at the intersection of the ruler with the meridian or east-west line. Najm al-Dīn claims that the points thus made will correspond to intersection of each horizon with the meridian or east-west line. It is not difficult to realise how egregious his mistake is, since his procedure is equivalent to a stereographic projection of an arc of length $d(\phi,\varepsilon)$, whilst the correct procedure should rather involve projecting an arc of length ϕ. Najm al-Dīn's error is difficult to explain, but may have arisen from his confusing a standard geometrical construction (which Najm al-Dīn correctly uses for constructing the meridians of his *shakkāziyya* plate – see below) with his 'easier' alternative method presented afterwards. The latter involves, appropriately this time, the half-excess of daylight.

2.2 *Astrolabes in three and one dimensions*

2.2.1 *The spherical astrolabe*

The spherical astrolabe is a globe on which the terrestrial markings (horizon, altitude and azimuth circles) are engraved, and on which a hemispherical rete can be adjusted for any (northern) latitude and can rotate freely. Historically it was derived from the planispheric astrolabe, probably for didactical reasons, since on this spherical instrument the visualisation of spherical astronomical phenomena occurs in a most 'natural' way.

It is not clear when or by whom the instrument was invented, but the available sources seem to suggest that its appearance in Islam occurred during the first half of the ninth century, but it is not excluded that it might have been known earlier in Hellenised Near Eastern communities. The earliest recorded text on its use is by Ḥabash al-Ḥāsib (*fl. ca.* 825–*ca.* 870), extant in three manuscript copies.[35] A more comprehensive treatise was composed by al-Nayrīzī (*fl.* 868–*ca.* 900),[36] who informs us that the only predecessor he knew to have written on it was al-Marwazī, who is none other than Ḥabash.[37] The text "On the Use of the Spherical Astrolabe" (*Kitāb al-ʿAmal bil-asṭurlāb al-*

[35] The treatise is entitled *al-ʿAmal bi-l-asṭurlāb al-kurī wa-ʿajāʾibuhu*. See Krause 1936, p. 447 and Sezgin, *GAS*, VI, p. 175. It is currently being investigated by Hussam Elkhadem (Brussels).

[36] Analysed in Seemann 1925, pp. 32–40 (with German translation of the introduction). The information in Maddison 1962, p. 102 (repeated in Lorch 1980, p. 154), according to whom the early ninth-century scientist al-Khwārizmī had already mentioned the spherical astrolabe, results from his confusing with the latter the late tenth-century encyclopaedist Abū ʿAbdallāh al-Khwārizmī, who indeed mentions this instrument in his *Keys of the Sciences*: see al-Khwārizmī, *Mafātiḥ*, p. 234.

[37] Seemann 1925, p. 33 and p. 62, n. 32.

kurī),[38] attributed to Qusṭā ibn Lūqā on the frontispiece of MS Leiden UB Or. 591, is in fact anonymous and perhaps posterior to al-Nayrīzī.[39] The title given on the frontispiece of the Leiden manuscript is "On the use of the sphere", which is the well-known treatise by Qusṭā extant in many copies, so there is no doubt that the attribution results from a confusion. This confusion between the globe (*dhāt al-kursī*) and the spherical astrolabe is also occasionally found in the modern literature.[40] The *Libros del saber de astronomía* composed for the King Alfonso X of Castilla in the thirteenth century also include a *Libro del astrolabio redondo* based on Arabic material.[41] The Arabic literature on the spherical astrolabe still merits detailed investigation.[42] Only two actual examples of spherical astrolabes survive.[43] al-Bīrūnī describes a spherical astrolabe constructed by Jābir ibn Sinān al-Ḥarrānī (*fl.* second half of the ninth century), who is probably al-Battānī's father.[44]

Najm al-Dīn's description of the instrument (Ch. 25) is more or less clear, but limited to the construction of basic markings. We note his remark that the rete cannot be depicted on the page because it is spherical; such warnings are frequent in his treatise.

2.2.2 *The linear astrolabe*

The linear astrolabe was invented by the twelfth-century mathematician Sharaf al-Dīn al-Ṭūsī.[45] Najm al-Dīn's description of this one-dimensional instrument (Ch. 78) is extremely confused and almost completely unintelligible. His account show some traces of contamination from his descriptions of two other linear instruments, namely, the observational 'ruler' of Ch. 105 and the Fāzārī balance featured in Ch. 95), on which see Section 6.1 on observational

[38] Seemann 1925, pp. 46–49.

[39] Already Suter (1900, p. 41) and then Seemann (1925, p. 6.) had expressed their doubts about the authenticity of the attribution, but Seemann (p. 49) nevertheless thought that (pseudo-)Qusṭā's treatise had been the model for al-Nayrizī. The same treatise is also preserved in MS Istanbul Topkapı Ahmet III 3505, also anonymous: see Krause 1936, p. 460 and Karatay 1966, no. 7046.

[40] E.g. in Sezgin, *GAS*, VI, p. 181.

[41] Seeman 1925; Viladrich 1987.

[42] In MS Mumbai Mulla Firuz 86, f. 50r–50v, for example, there is an anonymous fragment on the spherical astrolabe which should be compared with the other extant treatises mentioned above.

[43] See Maddison 1962 on a spherical astrolabe in the Museum of History of Science, Oxford, signed Mūsā and dated 885 H [= 1480/1], and Cannobio 1976, on an undated second specimen, with rete missing, constructed in Tunis, preserved in a private collection.

[44] See Seemann 1925, pp. 43–44, and Sezgin, *GAS*, VI, p. 162.

[45] On this author, see Anbouba's article in *DSB*, XIII, pp. 514–517 and Rashed 1986, I, pp. xxxiii–xxxvi. The principle of his linear astrolabe is described in Michel 1943 after al-Marrākushī's account, which has been published in Carra de Vaux 1895. Cf. Sédillot, *Mémoire*, p. 191. al-Ṭūsī's original treatise is preserved in several manuscripts (see Brockelmann, *GAL*, I, p. 622, SI, pp. 858–859) but remains unpublished.

instruments. Najm al-Dīn's incomplete and corrupt 'linear astrolabe' bears the following scales: (1) a non-uniform 'arc' scale, from 0 to 90, with divisions corresponding to the Sine; (2) a uniform 'Sine' scale, from 0 to 60; (3) another uniform scale, divided into 144;50 units (note that $144;50-60=84;50$, which is the Chord of 90° – cf. Ch. 59); and (4) a scale which is not explained, marked according to some tables (*jadāwil*). Najm al-Dīn makes also the remark that this instrument does not belong to the category 'astrolabes', but rather to the category 'rulers', and he notes that it was no longer found in his time.

2.3 *Non-standard planispheric astrolabes*

2.3.1 *Extended area of projection: the kāmil astrolabe*

On the "complete" (*kāmil*) astrolabe, the area of projection is extended so that the horizon circle can be completely represented on the plate. In such a case the radius of the extended plate will be given by the following expression:

$$r_{\max} = R_E \ \tan\left(\frac{90+\bar{\phi}}{2}\right),$$

so that the outermost day-circle on this plate will correspond to a declination of $\delta = -\bar{\phi}$. For latitudes below 30° this radius becomes too large in proportion to the ecliptic, but at a latitude of 36° the design is functional and also æsthetically quite appealing (see Figure 2.3). Najm al-Dīn devotes four chapters to the northern and southern varieties of the *kāmil* astrolabe, and to their quadrant versions. Ch. 5 is devoted to the northern *kāmil* astrolabe (plate illustrated in **P**:14v), Ch. 6 to the southern one and Ch. 7 to the northern (and southern) *kāmil* astrolabic quadrants.[46] On the illustrations in Chs. 5 and 6 the hour-lines are represented. On the *kāmil* astrolabe (especially the northern one) the approximation of these curves as circular arcs going through three points (see Section 2.1.3) is far less accurate than on the standard astrolabe. But the author is silent about this. Ch. 15 is, like Ch. 6, also devoted to the southern *kāmil* astrolabe, but the instructions are now more complete and also discuss the construction of the rete (which was omitted from Chs. 5–7). Ch. 15 purports to present an invention of the author (see the caption in **P**:22v), and the title promises an alternative construction method. Yet the texts of both chapters display no difference at all; the only element which in the illustration of the plate in Ch. 15 (**P**:22v) differs from that in Ch. 6 (**D**:78v) is that the hour-lines below the horizon have been left out and negative altitude circles are added in the region within the tropic of Cancer (which is the outermost

[46] The astrolabic quadrant is discussed in Section 2.4 below.

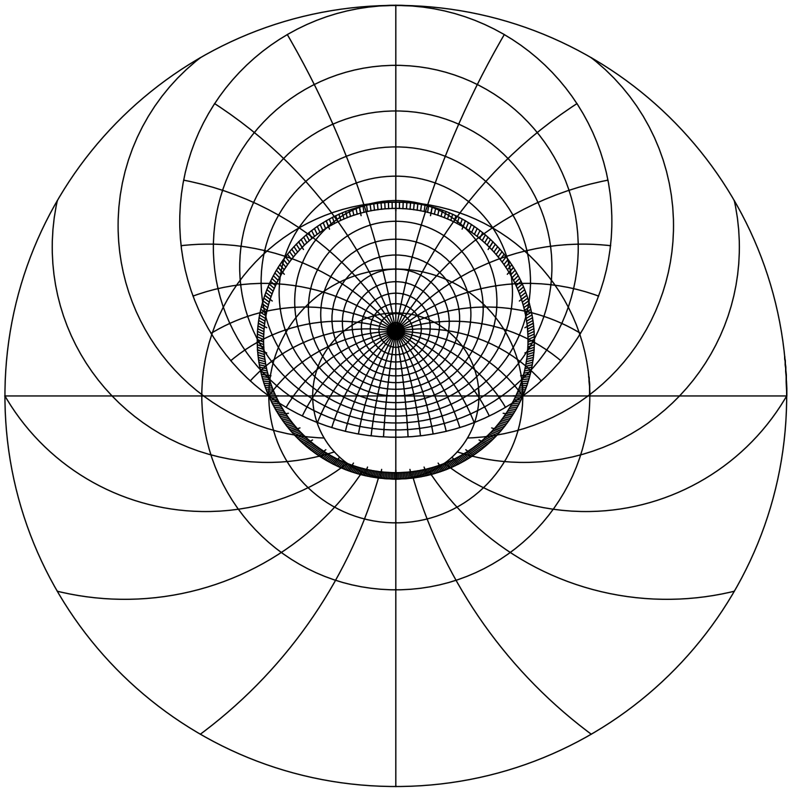

FIG. 2.3. The *kāmil* astrolabe (with accurate seasonal hour-lines)

tropic); the crescent-like region outside of this tropic and below the horizon is left empty. Ch. 15 includes a fine illustration (**P**:24r) of a rete with no less than 46 star-pointers (see Plate 17 and the list in Appendix C.2). In all four chapters the numerical value of the radius of the extended plate is given as 60;32, which is the result of the above expression, assuming $R_E = \frac{59}{3}$ and using Najm al-Dīn's Cotangent table (see above p. 53).

Astrolabes with extended radius of projection were not new in the fourteenth century. A solitary astrolabe plate preserved in the Davids Samling, Copenhagen (inv. no. 7/1983, diam. 137 mm), and featuring mixed projections of altitude circles, has a maximal effective diameter corresponding to a declination of *ca.* $\pm 36°$.[47] Also, a rete and a plate from a thirteenth-century Iranian astrolabe by Muḥammad ibn Abī Bakr al-Rāshidī (David Khalili col-

[47] The plate can be dated between the tenth and thirteenth centuries, and is clearly from al-ʿIrāq

lection, London, accession no. SC11, diam. 126 mm) have a maximal radius of projection corresponding to a declination of *ca.* $-35°$. On this plate (for latitudes 32°/34°) this is roughly midway between the tropic of Capricorn and the declination circle that would encompass the horizon.[48]

There are other astrolabic instruments mentioned in Mamluk sources with extended areas of projection. In his work on quadrants, the fifteenth-century author Ibn al-ʿAṭṭār mentions in passing a 'semicircle' whose circumference corresponds to one half of the horizon.[49] This instrument must be identical to one half of Najm al-Dīn's *kāmil* astrolabe, with the markings limited to the area above the horizon. On this semicircle, however, the ecliptic can no more be represented as a full circle and has to be folded in the same manner as on the astrolabic quadrant (see Section 2.4). Finally, one should bear in mind that Najm al-Dīn's *kāmil* astrolabe is not to be confused with some other instruments bearing the same epithet, of which I have recorded the following four examples:

1. al-Bīrūnī's astrolabe with orthogonal projection is called *kāmil*.[50]
2. al-Marrākushī's *kāmil* astrolabe refers to the *melon* astrolabe (whereas his astrolabe with orthogonal projection is called *ustuwānī*).[51] al-Marrākushī's account of the melon astrolabe is omitted from the otherwise exhaustive study by Kennedy, Kunitzsch & Lorch 1999.[52]
3. al-Mizzī's treatise on the *kāmil* astrolabic quadrant concerns a standard astrolabic quadrant which, in addition, is fitted with some kinds of sine markings.[53]
4. Ibn al-Shāṭir's *kāmil* quadrant is a special form of sine quadrant.[54]

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or Iran. On mixed projections, see Section 2.3.3. The maximal radius of projection was determined from measurements on photos kept in the Institut für Geschichte der Naturwissenschaften in Frankfurt.

[48] See Maddison & Savage-Smith 1997, I, pp. 210–211, no. 122. The declination of the outermost circle was determined from measurements on the published photograph of one side of the plate, serving a latitude of 34° (*ibid.*, p. 211). The Copenhagen plate is not dissimilar to the plate by al-Rāshidī, but I nevertheless think that it is by a different, and probably earlier, maker.

[49] MS Vatican Borg. 105, f. 4v:21-26 [*qism* 1, *faṣl* 8].

[50] See Puig 1996, p. 738.

[51] al-Marrākushī, *Jāmiʿ*, II, pp. 78–82 [*fann* 2, *qism* 6, *bāb* 3, *faṣl* 7]; the cylindrical projection is handled on pp. 83–85 [*faṣl* 9]. Sédillot, *Mémoire*, p. 183, simply listed the names of the instruments treated in *faṣl*s 6–10.

[52] Cf. p. 258, n. 2.

[53] *Risāla ʿalā Rubʿ al-muqanṭarāt al-kāmil*, MS Oxford Bodleian Huntington 193 (ff. 125r–136v).

[54] Ibn al-Shāṭir's treatise on its use is extant in the unique copy MS Princeton Yahuda 373, ff. 181v–188v.

2.3.2 *The "solid" astrolabe*

The "solid" (*mujammad* – Ch. 17) astrolabe has a single plate and is deprived of a rete. Instead, the ecliptic and the fixed stars are drawn on the plate in addition to the usual markings (equator, tropics, altitude and azimuth circles, hour-lines). The rotation of the sun and stars is simulated by an alidade or by a bead fixed on a thread which is attached at the centre, exactly as on the astrolabic quadrant (see Section 2.4). At least one example of such an astrolabe survives.[55] There exists a late fourteenth-century Hebrew description by Isaac al-Ḥadib (active in Sicily) of an instrument which is essentially a "solid" astrolabe on which a series of horizons appear instead of the altitude and azimuth circles for a given latitude, and which seems to be inspired by the *quadrans novus* of Jakob ben Makhir (*ca*. 1300).[56]

The stars featured on the illustration (**D**:38v) are all marked underneath the horizon, perhaps to avoid their crowding the altitude markings. Najm al-Dīn does not claim to have invented this instrument, and it was certainly widely known in his times. It should be observed that the astrolabic quadrant is essentially a "solid" astrolabe folded about the vertical axis, with the ecliptic folded again about the horizontal axis. But it remains a matter of speculation whether the "solid" astrolabe has been the direct precursor of the astrolabic quadrant, or conversely.

2.3.3 *Mixed projections*

Sometime during the late ninth or early tenth century, it occurred to a Muslim instrument specialist that an astrolabe on which different portions of the zodiacal belt of the rete are represented according to a combination of northern and southern projections would present an attractive design while retaining its full functionality. In the following I shall call such astrolabes 'mixed astrolabes'.[57] The earliest description of a mixed astrolabe is found in a short treatise on the astrolabe by the mathematician Ibrāhīm ibn Sinān (296–335 H/907–946) entitled *Risāla li-Ibrāhīm ibn Sinān ilā Abī Yūsuf al-Ḥasan ibn Isrāʾīl fī 'l-asṭurlāb* ("Letter of Ibrāhīm ibn Sinān to Abū Yūsuf al-Ḥasan ibn Isrāʾīl concerning the astrolabe"),[58] in which he mentions two basic types of mixed retes. Some decades later the late tenth-century geometer, astrologer

[55] National Maritime Museum, Greenwich, inventory number AST0557 (formerly A.26). The ecliptic is crescent-shaped and is underneath the horizon. This piece is made of wood with lacquered paper. It gives the impression of being late Ottoman, but the latitude for which it was made suggests Isfahan. See further Charette, "Greenwich astrolabes".

[56] Goldstein 1987, pp. 121–123.

[57] On mixed astrolabes, see Sédillot, *Mémoire*, pp. 181–182, Frank 1920, pp. 9–18, Wiedemann & Frank 1920-21, Michel 1976, pp. 69–70, Lorch 1994, and King 1999, pp. 345–348.

[58] Ibrāhīm ibn Sinān 1948, part 1, and idem 1983, pp. 309–317.

and astronomer al-Sijzī, who was active at the court of the Būyid *amīr al-umarāʾ* ʿAḍud al-Dawla (reg. 351–372),[59] composed a much lengthier treatise in which he presented over twelve different types of mixed retes, including several of his own invention, one more exotic than the other.[60] This work was the main source of al-Bīrūnī's descriptions in his *Istīʿāb*,[61] which in turn served as the main source of information to al-Marrākushī and Najm al-Dīn. While al-Marrākushī limited his account of mixed astrolabes to a strict paraphrase of al-Bīrūnī's *Istīʿāb*,[62] Najm al-Dīn attempted to impress his readership with more originality, but in this he had less success.

The two basic types of mixed retes, historically the first to have been devised, feature a different projection for each of the northern and southern halves of the ecliptic. When the northern signs (from Aries to Virgo) are represented by a northern projection and the southern signs (from Libra to Pisces) by a southern one, the resulting ecliptic belt resembles (at least for our modern eyes) a biconvex lens (see Fig. 2.4a); Muslim astronomers rather saw a resemblance with the leaf of the myrtle-tree (*ās*, *myrtus communis*),[63] and therefore it was named *al-asṭurlāb al-āsī*, "the myrtle astrolabe", which actually means something like "the astrolabe on which the ecliptic belt has the shape of a myrtle leaf". al-Bīrūnī also gives the alternative appellation *al-ahlīlajī*, "akin to a myrobalan".[64] Since with this scheme the complete ecliptic is projected within the circle of the equator, one could accordingly limit the area of projection of the rete and plate: given a fixed size of the astrolabe, this change of scale would result in a general increase of precision (of the ecliptic divisions, star positions and markings on the plates) by more than 50%. This ingenious idea, however, does not seem to have been applied to 'myrtle' astrolabes before the fourteenth century.[65] In the second case (see Fig. 2.4b)

[59] On al-Sijzī, see Sezgin, *GAS*, V, VI and VII, the article by Y. Dold-Samplonius in *DSB*, and Hogendijk 1996, pp. 1–3. In these biographies his association with ʿAḍud al-Dawla is never clearly stated, yet al-Bīrūnī qualifies al-Sijzī as "the geometer at the service of ʿAḍud al-Dawla" (*al-muhandis li-ʿAḍud al-Dawla* – al-Bīrūnī, *Istīʿāb*, MS Leiden UB Or. 591, p. 97). At least one work by al-Sijzī is indeed dedicated to this patron, namely the *Tarkīb al-aflāk* (Sezgin, *GAS*, VI, p. 225); al-Sijzī also made numerous instruments for his treasury (Lorch 1994, p. 237).

[60] The treatise is preserved in the unique copy MS Istanbul Topkapı Ahmet III 3342, ff. 123r–153v, 114r–122r, which might be lacunary. I am grateful to Dr. Richard Lorch (Munich) for giving me access to a preliminary version of his edition and translation of this work. A brief summary of its contents is given in Lorch 1994.

[61] MS Leiden UB Or. 591, pp. 94–103.

[62] See al-Marrākushī, *Jāmiʿ*, II, pp. 68–73 [*fann* 2, *qism* 6, *bāb* 3, *faṣl* 4].

[63] See the article "Ās" in *EI*², Suppl.

[64] al-Bīrūnī, *Istīʿāb*, MS Leiden UB Or. 591, p. 95.

[65] In the treatises by al-Sijzī and al-Bīrūnī, the outer limit of projection of the myrtle astrolabe is one of the tropics. The idea to fit a myrtle ecliptic belt over a universal stereographic projection appears simultaneously in the early fourteenth century in France, Morocco and Egypt. See Section 2.6.4. But the application of a myrtle rete together with either a standard plate bounded by the equator or with a series of *musattar* quadrants (see Section 2.4.2) only appears on the compound astrolabe of Ibn al-Sarrāj: see King & Charette, *Universal Astrolabe* (forthcoming).

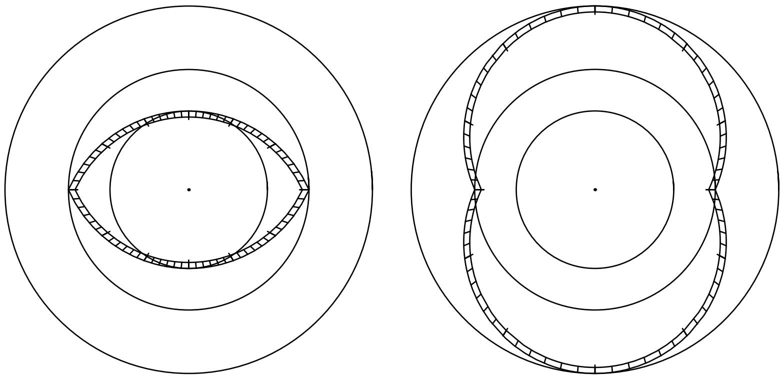

FIG. 2.4. The myrtle (a) and drum (b) ecliptic belts

the opposite projections are used for each half, and the resulting shape bears strong resemblance to the 'hour-glass version' of the Islamic percussion instrument *ṭabl*,[66] whence its epithet *al-muṭabbal*, "like a *ṭabl*".[67] al-Bīrūnī also mentions the alternative appellation *al-safarjalī*, "like a quince" (*cydonia odora*).[68] An obvious advantage of this rete is that the divisions of the ecliptic belt are more evenly-spaced than on a standard astrolabe, where the northern signs project on a small circular arc below the centre.

Before introducing the more complicated types of mixed retes, I briefly consider the earliest written source concerning the two basic ones, namely the treatise by Ibrāhīm ibn Sinān, who writes (in free translation):[69]

> Some people make the astrolabe with respect to the northern celestial pole – and this is the most common case. But a minority make it with respect to the southern pole; it results from this construction that the tropic of Cancer is the largest and outermost circle, [that is,] the nearest to the rim of the astrolabe. The innermost and smallest one is the tropic of Capricorn. The equatorial circle takes its (natural) position. Other people are less conventional: they make the astrolabe in two halves. One of them is (projected) from the northern pole, and the other half from the southern pole. There results that the ecliptic ring (*ḥalqa falak al-burūj*)

[66] See the article "Ṭabl" in *EI*^{2}, X, pp. 32–34.
[67] al-Marrākushī, II, p. 68 has *al-ṭablī*.
[68] al-Bīrūnī, *Istīʿāb*, MS Leiden UB Or. 591, p. 95.
[69] Ibrāhīm ibn Sinān 1948, part 1, pp. 2–3 and idem 1983, p. 309. Note that this text was not included in Bellosta & Rashed 2000, because the editors deemed its authenticity as dubious (a judgement I find arbitrary).

> has two halves like the ring of this figure, the one with the letters *AB*.[70] Among them some make it also (in the same manner) for the two other halves, so that its (ecliptic) ring corresponds to this figure with the letters *CD*;[71] I mean that the rete has its zodiacal signs arranged according to those two rings.

Neither Ibn Sinān nor al-Sijzī claims to be the inventor of any of these two basic types of mixed retes, which were probably invented *ca.* 250 H [= 864]. al-Sijzī says he thinks that the astrolabe-maker Nasṭūlus (*fl. ca.* 300 H)[72] was the inventor of a third kind, called the "crab" (*musarṭan*[73]) or "tree" (*mushajjar*) astrolabe.[74] Ḥājjī Khalīfa ascribes to one Muḥammad ibn Naṣr a treatise on the "winged" crab astrolabe (*al-asṭurlāb al-sarṭānī al-mujannaḥ*) in 23 chapters composed in 511 H [= 1117/18].[75] The four groups of three consecutive zodiacal signs of the ecliptic belt of this astrolabe are represented by alternate projections: southern from Aries to Gemini, northern from Cancer to Virgo, southern from Libra to Sagittarius, and northern from Capricorn to Pisces. This arrangement can be conveniently represented as SSS|NNN|SSS|NNN for the zodiacal signs, beginning with Aries. From now on I shall make use of this notation freely.

al-Sijzī and al-Bīrūnī describe eight more varieties of mixed retes, each of them adorned with a name referring to a plant or animal. Their designs are summarised in Table 2.1 on p. 71 and illustrated in Fig. 2.6. Of course these

[70] In the Hyderabad edition (1948) there is a diagram with a horizontal line *AB* and two circular arcs above and below with extremities *A* and *B*, in the shape of the myrtle rete depicted in Fig. 2.4a. In Saʿīdān's edition (1983) the figure is drawn in exactly the same manner, but without the lettering.

[71] In the Hyderabad edition there is a second diagram which is identical to the first one, except that the arcs above and below line *CD* are not represented in a perfectly symmetric way. In Saʿīdān's edition it is identical to the first one, although slightly larger; the lettering is again missing. It is clear from the text, however, that in the unique manuscript [Patna, Khuda Bakhsh 2519, f. 43r], this figure is corrupt and should represent a drum-shaped ecliptic belt instead: see Fig. 2.4b.

[72] On this personality, see King 1978b and King & Kunitzsch 1983; an astrolabe made by him is described in King 1995, pp. 79–83.

[73] al-Marrākushī, *Jāmiʿ*, II, p. 69 has *al-sarṭānī*.

[74] See the extract published in King & Kunitzsch 1983, p. 118. al-Sijzī also credits Nasṭūlus with the invention of the sundial on the alidade of the astrolabe (on this device see al-Bīrūnī, *Shadows*, pp. 238–240) and of "the construction of the azimuth [*ʿamal al-samt*] on the back of the astrolabe". I am here reproducing Lorch's unpublished translation; King & Kunitzsch have "the operation with the azimuth", which would correspond to *al-ʿamal bi-l-samt* – be it as it may, it is not clear what al-Sijzī is referring to; perhaps some procedure for finding the azimuth with the sine quadrant on the back?

[75] Ḥājjī Khalīfa, *Kashf al-ẓunūn*, I, col. 846 (see also p. 74, n. 85); the Ottoman bibliographer immediately adds that Abū Naṣr ibn ʿIrāq also wrote a treatise in 90 chapters "on its true (construction) by the method of the artisans", implying that this also concerns the crab astrolabe: but there exists another work by Abū Naṣr with a similar title, dealing with the standard astrolabe only (see Samsó 1969, pp. 36–37, 46–49, 75–88), so the possibility of a confusion cannot be excluded.

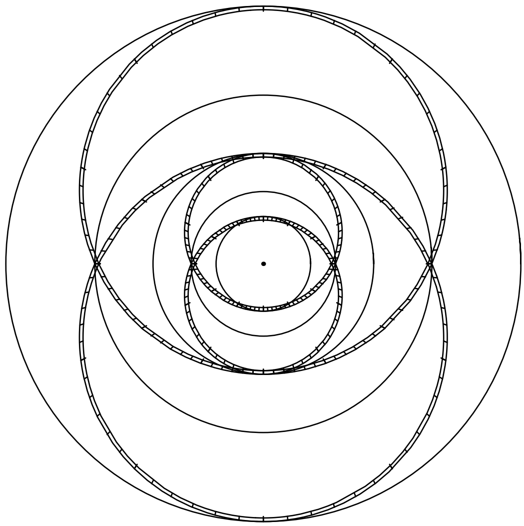

FIG. 2.5. Northern and southern ecliptic belts in two projection scales

are only a fraction of all possible combinations.[76] al-Sijzī introduced a further complication by using two different projection scales, i.e., assuming two different radii for the equator, on a single astrolabe. Each zodiacal sign can hence be represented in four different ways.[77] The two projection scales are chosen in such a way that the outermost tropic (i.e., Capricorn if the projection is northern) in the smaller projection coincides with the innermost tropic (i.e., Cancer if the projection is northern) in the larger one. A superposition of northern and southern ecliptic belts, each according to both scales, is illustrated in Fig. 2.5. al-Sijzī presents six different types of astrolabes of his own invention which are based of this principle, and al-Bīrūnī contents himself with describing the first one (the 'anemone'), albeit in a more detailed manner than al-Sijzī.[78] I have included the anemone-shaped rete in Table 2.1 because Najm al-Dīn has an astrolabe with this name. Otherwise, since mixed astrolabes with two different scales are not treated by him, I shall not consider

[76] An implicit criteria adopted for the design of mixed retes is that the resulting figure should be symmetric either with respect to the horizontal diameter or to the vertical one (or both). The total number of possible figures can be found by a simple combinatorial reasoning as $2 \cdot 2^6 - 2^3 = 120$, less 2 standard cases (only northern and southern projections): there are thus 118 different mixed astrolabe retes complying with the symmetry criteria.

[77] With two projection scales, there are $2 \cdot 4^6 - 4^3 = 8128$ different possible configurations of the ecliptic belt, from which all combinations involving only one scale of projection should be subtracted: $8128 - 2 \cdot 120$ yields 7888 possible combinations.

[78] al-Bīrūnī, *Istīʿāb*, MS Leiden UB Or. 591, pp. 100–103.

TABLE 2.1. The mixed retes of al-Sijzī and al-Bīrūnī †

1	*āsī* (myrtle)	NNN|NNN|SSS|SSS	SB	+
2	*muṭabbal* (drum)	SSS|SSS|NNN|NNN	SB	+
3	*musarṭan* (crab)	SSS|NNN|SSS|NNN	SB	∗−
4	*ṣadafī* (conch)	SNS|SNS|NSN|NSN	SB	
5	*samakī* (fish)	NNN|NNS|NSS|SSS	S	
6	*ʿaqrabī* (scorpion)	= myrtle	S	−
7	*bāṭī* (jug)	SSN|NNS|NSS|SNN	SB	
8	*narjisdānī* (narcissus-jar)	SNN|NNS|NSS|SSN	B	
9	*thawrī* (bull)	SSN|NSS|NSN|NSN	B	+
10	*jāmūsī* (buffalo)	NSS|NNS|NSS|NNS	B	+
11	*sulaḥfī* (tortoise)	NSN|NSN|SNS|SNS	B	+
12	*shaqāʾiqī* (anemone)‡	NNN|sss|nnn|SSS	SB	−

† The fourth column gives the sources: S = al-Sijzī, B = al-Bīrūnī. (Note that all astrolabes discussed by al-Bīrūnī are also featured in al-Marrākushī's *summa*.) In the last column the sign + indicates that Najm al-Dīn reproduced the instrument as in al-Bīrūnī, ∗ that he gives a different name to the same configuration, and − that he has an astrolabe with the same name but a different design. Not included in this list are the retes treated in Section 2.3.4, most of which Najm al-Dīn took from his predecessors.

‡ Large capitals refer to the large projection scale, and small capitals to the small one.

them any further. Najm al-Dīn's contemporary Muḥammad Ibn al-Ghuzūlī, however, revived al-Sijzī's idea on an instrument of his invention, which he called the *hilālī* (crescent) quadrant.

These mixed retes, of course, should be used in conjunction with plates which also feature mixed projections: the portions of the ecliptic in northern projection should be used together with altitude circles in northern projection, and likewise for those in southern projection. Since the representation of negative altitude circles in northern projection is exactly symmetric (with respect to the east-west line) to that of positive altitude circles in southern projection, the simplest possible plate for use with a mixed rete is one that displays all altitude circles, positive and negative. The convention of considering the altitude circles displayed in the lower half of the plate as 'negative' altitude circles is entirely my own, and does not correspond to the terminology used in the Arabic sources, where they are considered as positive altitude circles in the opposite projection and displayed upside-down. But this is very confusing, and I shall describe the projections used on astrolabe plates with the following convention. To represent the projections used for different sections of the sky, I shall use a four-letter notation AB|CD with arguments N or S: the first two letters refer to the eastern and western halves of the hemisphere above the

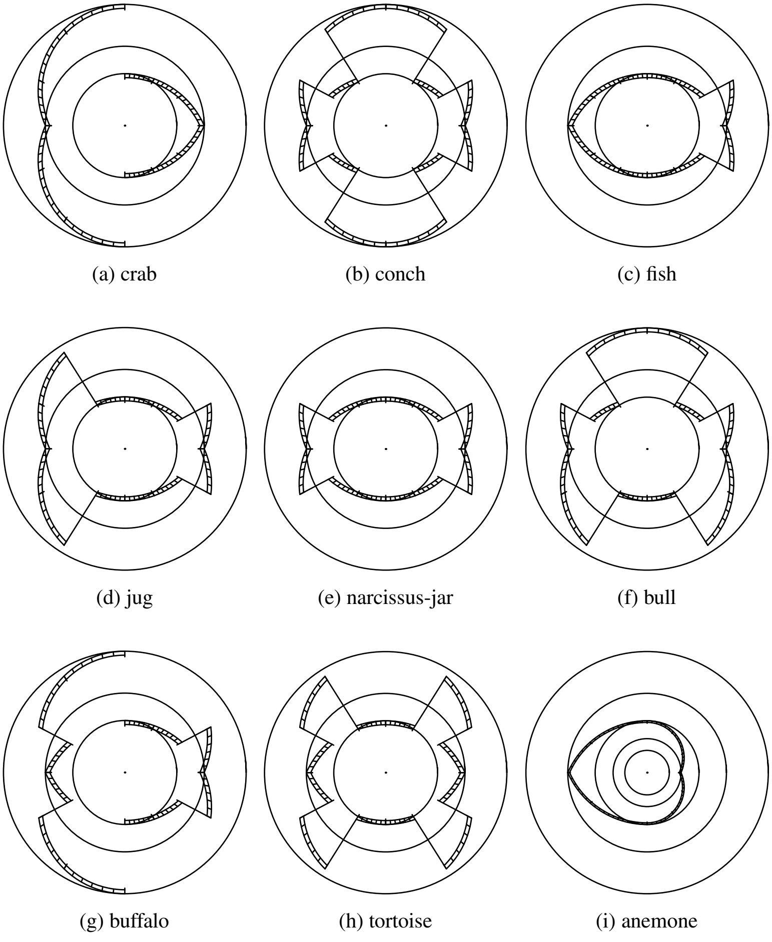

FIG. 2.6. al-Sijzī's and al-Bīrūnī's mixed retes

local horizon (that is, the visible sky), and the two last letters refer to the western and eastern halves of the hemisphere underneath the horizon. Thus, this order corresponds to a clockwise rotation on the astrolabe plate, starting with the eastern half of the visible sky. When no altitude circles are represented in a particular region it will be indicate with a hyphen (-). A standard astrolabe plate in northern projection without negative altitude circles, for example, will be designated NN|--. And a southern projection of both hemispheres on the whole plate will be designated SS|SS. A plate with configuration NS|NS is shown on Fig. 2.7a on p. 76.

Were mixed astrolabes actually made? In his *Traité de l'astrolabe*, Henri Michel devoted some space to the mixed astrolabes featured in al-Marrākushī's treatise (after Sédillot). Michel doubted that such curious astrolabes could have been actually constructed, and he concluded: "A notre avis, il ne s'agit que d'une coquetterie géométrique".[79] This is simply not true. In the Museum for the History of Science, Oxford, is preserved an astrolabe made in 728 H [= 1327/8] in Taza (Morocco) by ʿAlī ibn Ibrāhīm al-Jazzār[80] which features a myrtle rete. There also exist astrolabe plates with mixed altitude markings (one such plate is preserved in Copenhagen – see p. 64; several Moghul astrolabes also include feature mixed plates). But besides this rather meagre material evidence several written sources tell us that there existed from the ninth to the fourteenth centuries an established tradition of constructing mixed astrolabes. The testimony of Ibrāhīm ibn Sinān (see p. 68) is limpid and informs us that the construction, albeit by a minority of instrument-makers, of astrolabe retes of the myrtle and drum types was a well-known phenomenon in the early tenth century; otherwise he would not have taken the trouble to mention it to his addressee. In his treatise on astrolabes al-Sijzī reported that Nasṭūlus was the first to make a crab astrolabe.[81] He also stated clearly that he himself constructed astrolabes featuring mixed projections.[82] Five centuries later, in 830 H [= 1426/7], Ibn al-ʿAṭṭār wrote that the best examples of mixed astrolabes he knew were those made by al-Khamāʾirī, al-Mizzī and al-Maghribī.[83] It is most unfortunate that the astrolabes Ibn al-ʿAṭṭār had seen have not survived. There is no doubt, however, that these unusual instruments did not only exist in the imaginative minds of geometers,

[79] Michel 1976, p. 69

[80] On the name, see Calvo 1993, p. 19. See also p. 106 below.

[81] Quoted in King 1978b, p. 118.

[82] al-Sijzī made a fish (*samakī*) astrolabe for ʿAḍud al-Dawla, which he honorifically called the *ʿaḍudī* astrolabe (MS Istanbul Topkapı Ahmet III 3342, f. 153r:11-13). He also made an example of the anemone astrolabe of his invention (f. 151r:10).

[83] MS Vatican Borg. 105, f. 6r:35. At least fourteen astrolabes by al-Khamāʾirī (dated 609–634 H [= 1212–1237]) have survived, all of them standard, save some universal plates and some others with unusual trigonometric markings. A single astrolabe attributable to al-Mizzī (*ca*. 1325) is also standard. It is not clear who al-Maghribī is (perhaps al-Jazzār?).

but were also patiently crafted in brass.[84] I am aware of only two treatises on the *use* of mixed astrolabes.[85]

Najm al-Dīn's mixed astrolabes

Najm al-Dīn, in contrast to al-Marrākushī, does not reproduce al-Bīrūnī's description but rather presents a somewhat chaotic and idiosyncratic collection of mixed astrolabes, many of which he labelled as his own invention. This section of his treatise is probably the most enigmatic of all, for whereas the illustrations in both manuscripts are of unequalled accuracy and quality (and reveal sometimes also some originality), the accompanying text turns out to be a boring repetition of banal and vain instructions on the constructional elements of standard astrolabes. Oddly enough, the morphological peculiarities of the unusual instruments featured are almost never discussed. Therefore, I shall limit my commentary to a compact description of the mixed retes and plates illustrated in the manuscripts, following their order of appearance in the treatise. Most chapters cover two folios, the first one featuring the plate (text and illustration), and the second one, the rete.

Amongst the ten different kinds of astrolabes Najm al-Dīn claims to have invented, nine feature mixed projections. The southern *kāmil* astrolabe (Ch. 15) described above (see Section 2.3.1) is the first of the series. At the beginning of Ch. 37, Najm al-Dīn declares having stopped after the tenth invention in order not to make his explanations too lengthy. In the following, chapters featuring an astrolabe whose invention the author ascribes to himself are marked by an asterisk.[86]

Ch. 8: The spiral (*lawlabī*) astrolabe. The name seems to refer to the design of the plate; unfortunately, the illustration in **D** is incomplete but seems to suggest the combination ?N|NS[87] and the corresponding folio is lacking in

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[84] Myrtle astrolabes were also made in Europe: Jean de Lignères and Regiomontanus fitted their *sapheas* with a half-myrtle ecliptic belt (see p. 106, n. 183); there is also a medieval Italian example of a myrtle astrolabe preserved in Oxford (see Gunther 1932, II, pp. 319–320), which has only recently been properly identified: see King 1993c, pp. 50–52. Another myrtle astrolabe was devised *ca.* 1600 in Flanders by van Maelcote (see Michel 1976, pp. 71–72).

[85] The first one is entitled simply *Risāla fī 'l-ʿAmal bi-l-asṭurlāb al-musarṭan*, in 23 chapters, extant in MS Istanbul Topkapı Ahmet III 3509/3 (copied 676 H – see Krause 1936, p. 526); this could be identical to the treatise by one Muḥammad ibn Naṣr, also in 23 chapters, which is listed by Ḥājjī Khalīfa (see above p. 69, n. 75). The second one is by a student of Hibatallāh al-Baghdādī (died in Baghdad in 534 H [= 1139/40] – cf. p. 89, n. 121) named Abū Naṣr Aḥmad ibn Zarīr: *Maqāla fī 'l-ʿamal bi-l-asṭurlābāt al-gharība ka-l-musarṭan*, "Treatise on the use of the exotic astrolabes like the *musarṭan*"; it is preserved in MSS Leiden UB Or. 591, pp. 33–46, and Istanbul Topkapı 3505/4 (see Krause 1936, p. 484).

[86] Although the notice ascribing the invention to the author always appears below the figure of the *plate* with the mention 'The author of this book has invented *this* figure', the remark must in fact apply to the astrolabe as a whole.

[87] The negative altitude circles in northern projection in the lower-right quadrant are correctly drawn, but the representation of those in northern projection in the upper-right is faulty. In the lower-left, only a few altitude circles in southern projection are drawn around the nadir.

P. The text gives no clue whatsoever. The ecliptic belt is of the standard variety but it features a double scale corresponding to a northern and a southern projection, so that each degree is accompanied by its opposite degree (cf. Chs. 35 and 36).

Ch. 12: The crab (*musarṭan*) astrolabe. Plate: NS|NS (see Fig. 2.7a); this is a variant of al-Bīrūnī's plate for the *musarṭan* astrolabe, whereas the eastern and western halves of the plate have been interchanged.[88] The rete presents the combination NNN|NNN|SSS|SSS – which corresponds to the myrtle astrolabe! (Chs. 13 and 14) – whereas we would rather expect SSS|NNN|SSS|NNN.

Ch. 13: The northern counterbalancing (*mutakāfiʾ*) astrolabe. Plate: NN|SS; the name of the astrolabe obviously refers to the arrangement of the plate, which features two identical sets of markings symmetrically arranged with respect to the east-west line. Only the outline of the ecliptic belt has been sketched in **D** (and the corresponding folio is lacking in **P**). The intended combination, however, is clearly NNN|NNN|SSS|SSS. The text rightly mentions that this rete also serves the myrtle(Ch. 14) and the anemone (Ch. 16) astrolabes.

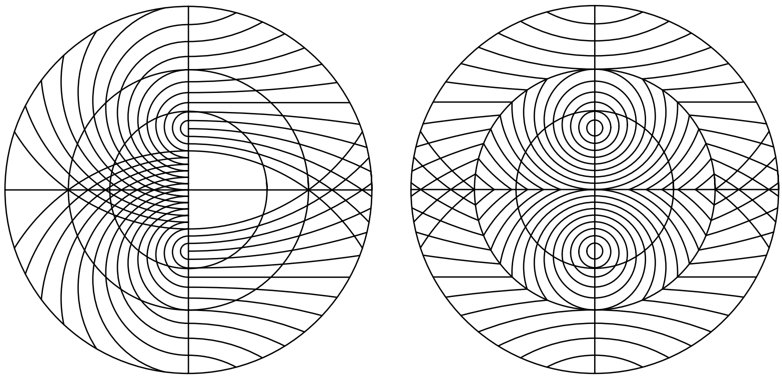
Ch. 14: The myrtle (*āsī*) and drum (*muṭabbal*) astrolabes. The same plate NN serves for both astrolabes. The rete of the drum astrolabe presents the combination SSSSSS|NNNNNN, as expected, and that of the myrtle astrolabe as been described in the previous chapter.

Ch. 16: The anemone (*shaqāʾiqī*) astrolabe. The plate is SN|SN, exactly as al-Bīrūnī's plate for the drum astrolabe (cf. Ch. 12 above), with the difference that the altitude circles on the right-hand side stop at the east-west line without overlapping.[89] In both manuscripts the altitude circles above 36° in the upper-left and below −36° in the lower-left are drawn with radii that are too small (the same problem occurs with the illustration of Ch. 36). The rete is not illustrated, but a note below the figure of the plate says that it is identical to the rete of the myrtle and *mutakāfi'* astrolabes (cf. Ch. 13). Najm al-Dīn's anemone astrolabe has nothing to do with the eponymous astrolabe invented by al-Sijzī, on which two projection scales are used. The reason for calling this astrolabe by that name must be related to the appearance of the plate, since it is the only aspect which distinguishes it from other types, but I cannot see what would make it resemble an anemone.

Ch. 18: The skiff (*zawraqī*) astrolabe. Again, this has nothing to do with al-Sijzī's invention of an astrolabe with fixed ecliptic and movable horizons (cf. Section 2.3.4). The plate of Najm al-Dīn's *zawraqī* is incompletely drawn

[88] al-Bīrūnī, *Istīʿāb*, MS Leiden UB Or. 591, p. 99, illustrated in Lorch 1994, p. 235, Abb. 6, which should be rotated 90° clockwise (the Arabic text is written sideways in the manuscript); the illustration in Frank 1920, p. 15, is, however, correctly oriented.

[89] In the illustration of al-Bīrūnī, *Istīʿāb*, MS Leiden UB Or. 591 on p. 95, the plate of the *musarṭan* also features a few concentric semicircles at the centre in the space left empty between the horizons at the left. This seems to be purely decorative. Cf. Frank 1920, p. 15.



(a) Plate of the crab astrolabe (Ch. 12) (b) Plate of the bull astrolabe (Ch. 20)

FIG. 2.7. Two plates of mixed astrolabes

in **D** (and the corresponding folio is lacking in **P**). Two horizons, southern and northern, are visible, and the central region delimited by them is left empty. Underneath the northern horizon are drawn altitude circles $-36°$ to $-90°$. A few altitude circles in southern projection are roughly sketched in the upper part of the plate. The rete has the combination SSS|NNN|SSS|NNN and is represented sideways with a rotation of 90° anticlockwise (cf. Ch. 23). This is identical with al-Sijzī's and al-Bīrūnī's crab rete.

Ch. 19: The jar (*bāṭī*) astrolabe. The plate has NN|SS outside of the equator; the portion inside of the equator has been left blank in **D** (and the corresponding folio is lacking in **P**), but probably the inverse arrangement SS was intended. The text barely makes any sense, though it might refer to a northern projection outside of the equator and a southern one inside. The rete has the same basic pattern as the myrtle astrolabe (NNN|NNN|SSS|SSS), but the ordering of the signs on the ecliptic belt has been rearranged according to the following permutation: 1,2,3|10,11,12|4,5,6|7,8,9 (with the convention Aries = 1, . . . , Pisces = 12), so that the resulting figure is quite different.

Ch. 20: The bull (*thawrī*) astrolabe. The plate has SS outside the equator[90] and NN|SS inside (see Fig. 2.7b). This scheme corresponds exactly with al-Bīrūnī's third mixed plate (MS Leiden UB Or. 591, p. 100) which he claims to have taken from al-Sijzī.[91] The rete is arranged SSN|NSS|NSN|NSN, which is identical with al-Bīrūnī's eponymous rete (compare entry 9 in Table 2.3.3

[90] With the same incorrect radii for $h < -36°$ as on the illustration of Ch. 16. This also occurs in Ch. 21.

[91] Those mixed plates are neither illustrated nor mentioned in MS Istanbul Topkapı Ahmet III 3342.

above). Although Najm al-Dīn suggests shaping the rete so that it resembles a bull, the illustration in the manuscripts is far less convincing as that in most manuscripts of al-Bīrūnī's treatise, where the rete really looks like the outline of a bull's head (see MS Leiden UB Or. 591, p. 99).

Ch. 21: The tortoise (*sulaḥfī*[92]) astrolabe. The plate has NN outside the equator and SS|SS inside. The rete has the arrangement NSN|NSN|SNS|SNS and is represented sideways with a rotation of 90° anticlockwise. The same rete is repeated in Chs. 27 and 28. It is identical with al-Bīrūnī's eponymous rete.

Ch. 22: The buffalo (*jāmūsī*) astrolabe. The plate has been left blank in **D** (and the corresponding folio is lacking in **P**), so it is not possible to recover its arrangement; the ecliptic on the rete has the configuration NSS|NNS|NSS|NNS, represented with an anticlockwise rotation of 90°, as on the illustration of al-Bīrūnī's buffalo astrolabe (MS Leiden UB Or. 591, p. 99).

Ch. 23*: The cup (*hanābī*) astrolabe. The altitude circles are wanting in **D** whilst the corresponding folio is lacking in **P**. The rete has the combination SSS|NNN|SSS|NNN, which corresponds to the drum astrolabe (hence it is identical, modulo rotation, to the rete in Ch. 18).

Ch. 24*: The melon (*mubaṭṭakh*) astrolabe. This is unrelated to the well-known astrolabe of the same name discussed in Section 2.3.4 below. Here it is a simple mixed astrolabe with plate NN|-- outside the equator and --|SS inside. The rete consists of a doubly-graduated semicircle attached to the centre by a radial bar, representing the half of the ecliptic in northern projection from Cancer to Capricorn. The arrangement of the signs on it is as follows (starting from the innermost extremity of the half-ecliptic): Cancer, Leo, Virgo, *Capricorn*, *Aquarius*, *Pisces*, (and in the opposite direction:) *Libra*, *Scorpio*, *Sagittarius*, Aries, Taurus, Gemini. The position of the signs set in italics is clearly absurd, since Virgo should be followed by Libra, etc., but both manuscripts have the same arrangement. Moreover, the clockwise graduation of one half of the signs necessitates using the western horizon as if it were the eastern horizon, and vice versa.

Ch. 27*: The frog (*ḍafdaʿī*) astrolabe. The plate presents the arrangement NS|NS as in Ch. 16, with the difference that the altitude circles on the right-hand side do overlap, and that the central region on the left-hand side delimited by the two horizons is filled with altitude circles in southern projection. The rete – identical with that in Ch. 21 – is illustrated on Plate 2.

Ch. 28*: The eagle (*ʿuqābī*) astrolabe. The plate has NS|SS; the central region on the left-hand side delimited by the two horizons is filled with altitude circles in the projection that pertains to their respective quadrant (i.e., southern in the upper-half, and northern in the lower half). The rete is the same as above.

[92] The manuscripts have rather *sḥlfī* and *zḥlfī*; see the remarks on p. 41.

Ch. 33*: The southern *mutakāfiʾ* astrolabe. The name of this astrolabe is a consequence of the fact that its plate SS is the symmetric opposite of the plate of the northern *mutakāfiʾ* (Ch. 13), which has the arrangement NN|SS. Its rete, however, is completely different: at first sight it seems to have two complete ecliptics in northern and southern projections. But the arrangement of the signs rather correspond to the superposition of a myrtle and a drum ecliptic which are oriented in two opposite directions. A rete with exactly the same design is described by al-Sijzī (but not by al-Bīrūnī).[93] On Najm al-Dīn's version, oddly enough, the myrtle portion also features a second graduation which runs clockwise (compare Ch. 24). Najm al-Dīn, who ascribes to himself the invention of the plate, did not get the idea from al-Sijzī, as he certainly did not have access to his treatise on the astrolabe.

Ch. 34*: The scorpion (*ʿaqrabī*) astrolabe. Its plate is more complicated that those we have seen until now (see Plate 3). The upper half has the combination SN and the altitude circles in the upper-right quadrant do not go beneath the east-west line. The lower half corresponds to a standard northern projection seen sideways, the zenith being on the western line. The altitude circles from the lower-left quadrant continue in the upper-left quadrant to reach the southern horizon. The rete is the same as on the myrtle astrolabe.

Ch. 35*: The diverging (*mutadākhil mutakhālif*) astrolabe. The design of its plate follows the principle established in the preceding chapter: the left-hand side features a southern projection in the upper-half and a northern one in the lower-half (exactly as the plate of Ch. 33). The rest of the plate, including the central portion between the two horizons on the left, is filled with altitude circles of a single projection rotated sideways, with the zenith on the left-hand side. The rete has a doubly graduated ecliptic as in Ch. 8.

Ch. 36*: The fitting (*mutadākhil muwāfiq*) astrolabe. Its plate with the combination SN|SN presents a variant of those featured in Chs. 16 and 27. The altitude circles on the left-hand side are in fact identical with those in Ch. 28, and the altitude circles on the right-hand side are like those in Ch. 27, but here the altitude circles continue beyond the horizons in each quadrant in order to fill the small area limited by the horizons and the outermost tropic. The rete is the same as in the preceding chapter.

Ch. 37*: The crescent (*hilālī*) astrolabe. The plate has the arrangement SS as in Ch. 33, and the central area between the horizons features in each quadrant two identical non-overlapping sets of northern altitude circles near the zenith. For the ecliptic belt see Section 2.3.4 below.

[93] MS Istanbul Topkapı Ahmet III 3342, 114v–115r. The accompanying plate has northern *and* southern altitude circles drawn between the equator and the outermost tropic; curves for the seasonal hours are drawn in the innermost region for both projections. This astrolabe is said to be the size a palm of a hand.

2.3.4 *Other types of retes*

The ruler and cross astrolabes

These two types of astrolabes are taken from al-Bīrūnī's *Istīʿāb*.[94] According to al-Bīrūnī, the cross astrolabe was invented by al-Sijzī on the basis of the ruler one. Neither of them, however, are mentioned in the unique extant manuscript of al-Sijzī's work.[95] Both are nothing but standard astrolabes with simplified retes. On the ruler astrolabe (Ch. 38) the usual rete is replaced by a simple alidade which bears a scale with the zodiacal signs and their divisions corresponding to the radii of their respective day-circles. We hence lose the conversion of ecliptic longitudes to equatorial ascensions usually afforded by the rete. In order to perform many of the standard operations with this astrolabe, we need a table of right ascensions (al-Bīrūnī rather refers to a table of oblique ascensions). According to al-Bīrūnī, this table can be engraved either on the mater along the circle of Capricorn, or on the back of the astrolabe.[96] The cross astrolabe is a rather refined variant of the ruler one. The zodiacal scale is located on a bar perpendicular to a radial ruler and tangent to the equatorial circle. The radii of the day-circles defining the divisions of its scale correspond to the same projection as the drum astrolabe (i.e., northern projection of the southern signs and southern projection of the northern signs). This astrolabe also requires a table of ascensions.

Najm al-Dīn's 'cross' astrolabe (Ch. 11), however, is completely different from that of al-Sijzī. Whereas one half of its ecliptic ring, from Aries to Virgo, is standard, the other half is replaced by the corresponding segment of a ruler-shaped ecliptic, located along the upper vertical radius of the rete. The resulting shape actually bears little resemblance to a cross.

The spiral and the skiff astrolabes

The names of two more kinds of astrolabes mentioned by al-Bīrūnī are used by Najm al-Dīn, but they designate completely different instruments. These are the skiff (*al-zawraqī*) and spiral (*al-lawlabī*) astrolabes. In their original version described by al-Bīrūnī, they feature unusual retes whose forms are not obtained by projection. They are reported by al-Bīrūnī to have been invented by al-Sijzī.[97] Yet Najm al-Dīn's skiff (Ch. 18) and spiral (Ch. 8) astrolabes have nothing in common with them, for they belong to the category of astrolabes with mixed projections discussed above.

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[94] MS Leiden UB Or. 591, pp. 106–107. Cf. Frank 1920, pp. 21–22. See also al-Marrākushī, *Jāmiʿ*, II, pp. 75–76 [*fann* 2, *qism* 6, *bāb* 3, *faṣl* 6, which also discusses the spiral astrolabe (see below)].

[95] See n. 60 above.

[96] In al-Marrākushī's treatise (*Jāmiʿ*, II, p. 76), the illustration of the ruler astrolabe bears a schematic representation of a table of right ascensions, displayed on the front around the tropic of Capricorn.

[97] Again, they are not mentioned in al-Sijzī, MS Istanbul Topkapı Ahmet III 3342.

On the authentic skiff astrolabe, the ecliptic and fixed stars are drawn on the plate, and the rete consists of a movable device representing two horizons (or eight half-horizons).[98] The special configuration of this astrolabe, on which the terrestrial parts rotate over a fixed celestial part, has led al-Bīrūnī to evoke the possibility of the daily rotation of the earth; he declared that it was an "uncertain question, difficult to resolve", and added that only natural philosophers were able to provide an answer to it.[99] al-Marrākushī paraphrased al-Bīrūnī on this, and then expressed his own opinion on the matter:

> al-Bīrūnī said: "This is a doubtful (question), difficult to establish". One wonders how he could have considered difficult something whose wrongness is most evident. (For) this is a matter whose erroneousness has conclusively been demonstrated by Abū ʿAlī ibn Sīnā in the *Kitāb al-Shifāʾ*, and by [Fakhr al-Dīn] al-Rāzī in *Kitāb al-Mulakhkhaṣ* and in several other books of his. Others [have also discussed] whether (the movement) pertains to the earth (as the *zawraqī* would suggest) or to the heaven, as exemplified by the (standard) astrolabe.[100]

Here is a unique example of an astronomical instrument which served as a pretext for introducing a discussion of a difficult cosmological problem.[101]

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[98] al-Sijzī, MS Istanbul Topkapı Ahmet III 3342, ff. 114r–114v; al-Bīrūnī, *Istīʿāb*, MS Leiden UB Or. 591, pp. 104–106. Cf. Frank 1920, pp. 18–21. See also al-Marrākushī, *Jāmiʿ*, II, pp. 74–75 [*fann* 2, *qism* 6, *bāb* 3, *faṣl* 5].

[99] al-Bīrūnī, *Istīʿāb*, MS Leiden UB Or. 591, p. 104; this passage is translated in Wiedemann 1912b. The question whether the earth could have a daily rotation around its axis was discussed and rejected by Ptolemy (*Almagest*, I.7); according to Simplicius, Heraclides of Pontus and Aristarchus had favoured the rotation of the earth as a possible explanation of the apparent daily celestial movements (see Grant 1994, p. 638). In his book on India, al-Bīrūnī mentioned the opinions of various Indian scholars on this matter, and added that the rotation of the earth, whilst extremely difficult to prove or disprove, does not affect the validity of the results of the science of astronomy: see Wiedemann 1909 and Carra de Vaux 1921–26, II, pp. 216–218. In his *Qānūn* (ed. Hyderabad, 1954, I, pp. 42–53), he discussed the question further and finally offered a decisive argument in favour of the immobility of the earth; this and other passages by al-Bīrūnī pertaining to the question are studied in Pines 1956 (unaware of Wiedemann); cf. Nasr 1978, pp. 135–136 (based on the same sources as Pines), where the daily rotation of the earth is confused with heliocentrism. Naṣīr al-Dīn al-Ṭūsī presented a different physico-philosophical argumentation against the rotation of the earth: see Ragep 1993, § II.1 [6] (with commentary in vol. II, pp. 383–385). Ṭūsī's student Quṭb al-Dīn al-Shīrāzī had a yet more elaborate discussion on the whole issue, which is paraphrased in Wiedemann 1912a, pp. 415–417; see also Ragep 1993, II, p. 384. On other Muslim authors, see also Wiedemann, *Aufsätze*, I, pp. 84–86, 171–172. The cosmological discussions on this question in medieval and early-modern Europe are presented in Grant 1994, pp. 637–673.

[100] This passage has also been reproduced and translated in Carra de Vaux 1895, p. 466 (second half of the footnote). Ibn Sīnā summarised Ptolemy's views against the rotation of the earth in his *al-Shifāʾ*, *al-Riyāḍiyyāt 4: ʿIlm al-hayʾa*, *faṣl* 5 of the first *maqāla*, esp. pp. 25–26. His own refutation of terrestrial motion is in *ibid.*, *al-Ṭabīʿiyyāt 2: al-samāʾ wa-l-ʿālam*, *faṣl* 8. al-Rāzī's treatise *al-Mulakhkhaṣ* is not accessible to me.

[101] It should be borne in mind, however, that the design of instruments seldom have a speculative cosmological dimension. James Bennett (in a paper delivered at the symposium 'Cer-

At the beginning of the fourteenth century, Ibn al-Shāṭir designed a universal astrolabe he called *al-āla al-jāmiʿa*, which is actually an extension of the *zawraqī* astrolabe.[102]

The *lawlabī* astrolabe has its ecliptic belt shaped like a spiral; it is described by al-Bīrūnī and al-Marrākushī (who calls it *ḥalazūnī*).[103] I am not aware of any other occurrence in the literature. This spiral as it is defined by al-Bīrūnī can be defined mathematically as the polar plot of the function

$$R_E \tan\left(\frac{90^\circ - \delta(\theta/3)}{2}\right)$$

in the interval $(-270^\circ \leq \theta \leq 270^\circ)$. Each quadrant of the spiral serves 30° of longitude for two zodiacal signs, and the graduation runs from the beginning of Capricorn at the outermost extremity to the end of Gemini at the innermost one, and then it runs back clockwise from the beginning of Cancer to the end of Sagittarius. The disposition of the star-pointers is as on a standard astrolabe.

The crescent astrolabe

The ecliptic belt of the crescent (*hilālī*) astrolabe is obtained from a regular one by folding its lower half (summer signs: Aries to Virgo) over the upper half (winter signs: Libra to Pisces), hence the resemblance with a crescent. An astrolabe with the same name and with the same rete is described by al-Sijzī; the plate is reduced to the upper half only.[104]

It is not necessary to assume any direct influence of al-Sijzī on Najm al-Dīn, however, since the idea of a crescent-shaped ecliptic was applied already to the astrolabic quadrant, which seems to have originated in the twelfth century (on the astrolabic quadrant see Section 2.4). On Najm al-Dīn's version, however, the folding the ecliptic belt is purposeless.

The melon astrolabe

al-Bīrūnī's comprehensive work on the astrolabe was for Najm al-Dīn certainly as important a source as it had been a generation previously for al-Marrākushī. However, whereas the latter presents an intelligent paraphrase of

tainty, Doubt, Error', Frankfurt am Main, 17–18 November 2001) appropriately remarks that pre-Copernican terrestrial globes often rotate about an axis, without any implication beyond the purely practical.

[102] Two examples made by Ibn al-Shāṭir himself are extant (both dated 733 H [= 1332/33]), alas without the rete; see Mayer 1956, pp. 40–41.

[103] al-Bīrūnī, *Istīʿāb*, MS Leiden UB Or. 591, pp. 107–108; al-Marrākushī, *Jāmiʿ*, II, p. 77. See n. 94 above.

[104] MS Istanbul Topkapı Ahmet III 3342, f. 153v continuing on f. 114r. al-Sijzī declares that he has made such an astrolabe for the treasury of ʿAḍud al-Dawla and that he also wrote a treatise on its use.

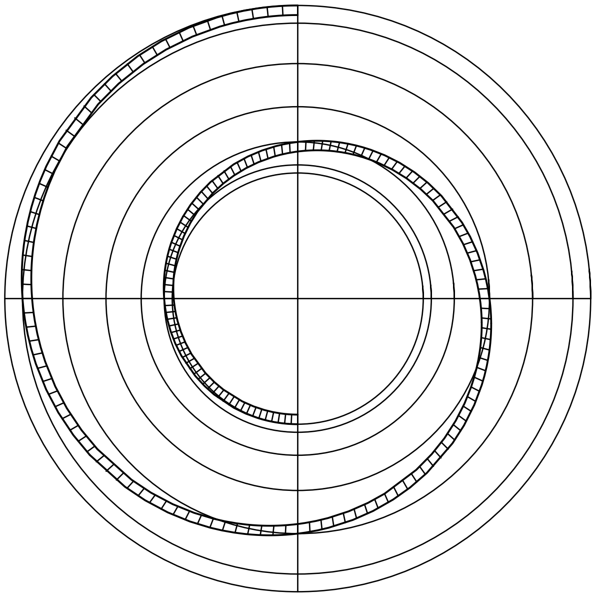

FIG. 2.8. The rete of the spiral astrolabe

al-Bīrūnī's non-standard astrolabes, following the same order, Najm al-Dīn's direct use of al-Bīrūnī is much more elusive. Ch. 24, however, is one of only four chapters where Najm al-Dīn mentions his predecessor by name.[105] Reading al-Bīrūnī, Najm al-Dīn realised that the status of the melon astrolabe was controversial among the specialists; this is the reason why he chose not to present its construction in his treatise, but rather to substitute another variant of the standard astrolabe for it. One can surmise that Najm al-Dīn was not capable of understanding the melon astrolabe and the controversy surrounding it, and thus refrained from dealing with this unusual instrument. Nevertheless, he made a few valid general statements about it, namely, that it resembles a (flattened) spherical astrolabe, that its horizon has not the usual shape, and that its use is unlike that of the standard astrolabe.[106]

From his textual description of the construction of the plate and rete, nothing specific can be deduced about what could distinguish from a standard astrolabe the variant he introduced in lieu of the melon astrolabe. But the illustrations, again, tell us more. The plate illustrated (**D**:45r and **P**:43v) is exactly like on a standard northern astrolabe for latitude 36°, except that the portion

[105] al-Bīrūnī is also mentioned in Chs. 12, 37 and 38.

[106] A detailed study of the melon astrolabe is Kennedy, Kunitzsch & Lorch 1999.

of the plate within the equatorial circle is rotated by 180° (for no apparent reason).

Its rete has a semicircular form; the left-hand side of the usual ecliptic belt has been left out, so that it bears a double graduation. The quadrant with the northern signs is graduated as we should expect (anticlockwise from the bottom): Cancer, Leo, Virgo and then, in the reverse direction, Aries, Taurus, Gemini. The southern part of the ecliptic, however, has the remarkable property that the position of the signs are reversed by 90°. Thus, we have (again anticlockwise) Capricorn, Aquarius, Pisces; and in the reverse direction: Libra, Scorpio, Sagittarius. This disposition of the signs does not make sense, and they should therefore be restored to their usual order.

2.4 *Astrolabic quadrants*

The standard astrolabic quadrant was already well-known in Egypt in the twelfth century.[107] It consists of the eastern half of the markings of an astrolabic plate, and the resulting semicircle is further cut off horizontally underneath the horizon in order to keep only the markings representing the visible sky: the 'quadrant' thus includes more than a quarter circle of markings. One half of the ecliptic is also drawn on the quadrant, with the graduation for the winter solstice coinciding with the upper extremity of the vertical diameter; the lower half of the ecliptic (summer signs) is furthermore folded over the upper half, and the result is a half-crescent. This is graduated in the same manner as the ecliptic belt on standard astrolabes, but each graduation now serves two points of the ecliptic having the same declination. Fixed stars can also be marked by dots on the surface of the quadrant. The rotation of the sun (or any star) is simulated by a thread attached to the centre, along which a small bead can be set at a position corresponding to the appropriate declination. The use of this instrument is fundamentally the same as that of the astrolabe.

The astrolabic quadrant became extremely popular from the fourteenth century onward and in the Near East it generally replaced the astrolabe for practical purposes, which remained the expensive and prestigious scientific *objet d'art* it had always been.[108] Since astrolabic quadrants were usually drawn on a sheet of paper lacquered on wood, they were very cheap to produce. They were also more accurate than astrolabes of comparable size, since

[107] On the earliest treatise on the use of this instrument, see King 2002 and idem, *SATMI*, VIII, § 6.3. On the astrolabic quadrant in general, see Würschmidt 1918; Würschmidt 1928; Schmalzl 1929, pp. 33–62; Janin & Rohr 1975.

[108] This is not to deny that astrolabes were used for practical purposes, for many of the extant pieces do indeed reveal traces of usage, and several medieval authors also tell us about their concrete use of an astrolabe, either for calculation or for observation of altitudes. See for example Ibn Yūnus' quotation of al-Māhānī in Caussin 1804, pp. 87, 89 (pp. 88, 90 of the translation).

drawing lines and scales with ink on paper or wood is incomparably easier than engraving them on metal; also the position indicated by a small bead on a thread is less subject to instrumental errors than that indicated by the ecliptic scale and star-pointers on the rete of an astrolabe. Only one wooden specimen is known from the Mamluk period, all others are Ottoman and date from the seventeenth century onward. But we know from Mamluk sources that wood was a favourite material for portable instruments like quadrants.[109] Combined with a sine quadrant on the back the astrolabic quadrant became the favorite tool for teaching astronomy in Mamluk and Ottoman mosques and madrasas, as attested by the many treatises on the use of these instruments and the multitudinous manuscript copies thereof.[110]

The inventor of the astrolabic quadrant, whoever he was, had an easy task, since all elements of his invention were already featured on various existing instruments. First, solving problems within a 'quadrant' (or more exactly, within one half of the standard altitude markings) was a characteristic of mixed astrolabes. Second, the idea of having a fixed ecliptic was applied on the *zawraqī* astrolabe,[111] while the idea of simulating the rotation of the sun or a star with a thread (or an alidade) was applied on the ruler astrolabe. Third, the folding of an ecliptic belt was a feature of the crescent astrolabe of al-Sijzī.

Concerning Najm al-Dīn's description of standard astrolabic quadrants (Ch. 3) there is little to say: the text is strictly concerned with the altitude and azimuth circles, and omits the tracing of the ecliptic, likewise wanting on the illustrations, which otherwise are far more informative than the text. Ch. 65 features an astrolabic quadrant for a latitude of 48°, which corresponds to the end of the seventh climate. It is accompanied by a table for that particular latitude similar to that in Ch. 1. The reason for including this chapter is supposedly to explain a particular error related to using the astrolabic quadrant at higher latitudes. Unfortunately, Najm al-Dīn's words on this matter are incomprehensible.

A quadrant with extended (*kāmil*) radius of projection is also featured in Ch. 15: see Section 2.3.1.

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[109] Most extant Mamluk pieces are made of brass (6 pieces, out of which 5 are by al-Mizzī – see p. 14, n. 55). The only two that are not are signed by Abū Ṭāhir: one is made of ivory (see King 1991, p. 182) and another one out of wood (preserved in the Chester Beatty Library, Dublin). There is little doubt, however, that the vast majority of quadrants were made out of wood, even as early as the ninth century. At the end of his comprehensive treatise on quadrants Ibn al-ʿAṭṭār gives detailed instructions on the preparation of varnish for lacquering wooden quadrants (see MS Vatican Borg. 105, ff. 7r:18–7v). A more extensive treatise on the chemical and metallurgical aspects of the construction of instruments by a seventeenth-century *muwaqqit* is analysed in Siggel 1942; cf. King, *Survey*, no. C124.

[110] See e.g. King, *Fihris*, II, Sections 4.4–4.5 and Ihsanoğlu, *OALT* (index of titles).

[111] We leave out the solid astrolabe since it might not necessarily be anterior to the astrolabic quadrant.

2.4.1 *Astrolabic quadrants with mixed projections*

Najm al-Dīn pushed his fantasy as far as imagining astrolabic quadrants with mixed projections. But these instruments, of course, have no rete, so the only elements affected are the altitude circles. In principle it would be possible to introduce some variations in the shape of the ecliptic on the quadrant, but Najm al-Dīn refrained from such a futile exercise. Yet the names he gave to these quadrants are directly taken from his repertory of mixed astrolabes; still, the link between an astrolabe and its presumed companion quadrant is rather pointless.

The text accompanying the illustrations of these quadrants is as disappointing as in the case of the mixed astrolabes: it is nothing but a vain repetition of the usual instructions on how to trace the altitude circles, with no reference or hardly any reference to the unusual configuration of the markings. Hence, the following descriptions of the individual quadrants will be based exclusively on the illustrations. On these quadrants only the altitude circles are traced.[112] Furthermore, the text omits in all cases to explain how the ecliptic should be drawn. For each of the quadrants (except in Ch. 45) the outer rim is extended over 90° so that the innermost tropic can be represented as a complete semicircle.

Ch. 42: The spiral astrolabic quadrant is nothing more than a standard quadrant in southern projection, and the text repeats with a more obscure phrasing the information contained in Ch. 3.

Ch. 44: The counterbalancing (*mutakāfiʾ*) astrolabic quadrant features a northern projection. In addition, a southern horizon is also represented (its goes from the meridian to the east line). The space between both horizons is filled with altitude circles in southern projection.

Ch. 45: The myrtle or drum astrolabic quadrant consists in a superposition of northern and southern projections.

Ch. 46: The skiff astrolabic quadrant has a northern and a southern horizon. The space above the east line and the northern horizon is filled with southern altitude circles. The space below the east line and above the northern horizon is filled with northern altitude circles. The space between the lower limit of the quadrant, below the northern and southern horizons, is again filled with southern altitude circles.

Ch. 47: The tortoise astrolabic quadrant has northern markings outside of the equator and southern ones within (compare Ch. 21).

Ch. 48: The bull astrolabic quadrant. On the illustration in **D** (the corresponding folio is lacking in **P**), one can only see a northern horizon going from the meridian line to the east-west line, and a few northern altitude circles

[112] In Ch. 42 the construction of azimuth circles is explained, but then it is noted (as in the other chapters as well) that it is better to leave them out and to use a azimuthal quadrant instead. On none of the illustrations of 'mixed' astrolabic quadrants are the azimuth markings represented.

around zenith as well as a few southern ones below the east-west around the nadir. It is thus possible that the markings correspond to those of the bull astrolabe (Ch. 20).

Ch. 49: The jar astrolabic quadrant. The illustration in **D** is blank and the corresponding folio is lacking in **P**, but perhaps the same design as in Ch. 19 was intended. The text, as usual, gives no clue.

This chapter ends with a general remark concerning a special aspect of the *use* of astrolabic quadrants, the only instance in the whole treatise of a discussion of the use of an instrument. This passage makes no sense to me.

2.4.2 *The* musattar *quadrant*

The fifteenth-century author Ibn al-ʿAṭṭār attributes the invention of this type of astrolabic quadrant to Ibn al-Sarrāj.[113] It is indeed an essential feature of the celebrated astrolabe he made in the year 729 H [= 1328/9], on which each of a subset of plates bears four *musattar* quadrants, each serving a different latitude, for each 3° from 3° to 90°. Ibn al-Sarrāj also wrote a treatise on its use.[114] It is probable that Najm al-Dīn, who devotes Ch. 55 to this quadrant, learned of it through his contemporary Ibn al-Sarrāj, directly or otherwise. This quadrant became rather popular among Ibn al-Sarrāj's successors. Other treatises on its use are known by al-Mizzī, al-Bakhāniqī, Shams al-Dīn al-Khalīlī, Ibn al-Majdī (2 different treatises), al-Tīzīnī, Sibṭ al-Māridīnī and Muṣṭafā ibn ʿAlī al-Qusṭanṭīnī. al-Wafāʾī also wrote a section on the use of the *musattar* plates featured on Ibn al-Sarrāj's spectacular compound astrolabe in his treatise on the use of this complex instrument.[115]

This quadrant is bounded by the equatorial circle, rather than by one of the tropics, inside of which altitude circles in southern projection are superposed upon altitude circles in northern projection. Alternatively, these markings can also be considered as resulting from the folding of the lower half of an astrolabe plate with a complete set of altitude circles (above and below the horizon) over its upper half. This explains the alternative name given to this quadrant by later authors such as al-Mizzī, whose treatise on its use is entitled *Risāla fī 'l-ʿAmal bi-rubʿ al-dāʾira al-mawḍūʿ ʿalayhi al-muqanṭarāt al-maṭwiya* ("Treatise on the quadrant on which the altitude circles are folded").[116] The ecliptic on this quadrant has the shape of one quarter of a myrtle ecliptic (see 2.3.3), and this is probably the reason why the *muwaqqit* at the

[113] MS Vatican Borg. 105, f. 4r:1.

[114] *[Risāla] fī 'l-ʿAmal bi-rubʿ al-muqanṭarāt al-maqṭūʿa min madār al-ḥamal wa-l-mīzān*, MS Berlin Landberg 390, ff. 15r–17r (= Ahlwardt no. 5859).

[115] For full discussion of the history of *musattar* markings the reader is referred to the forthcoming publication King & Charette, *Universal Astrolabe*.

[116] Extant in three copies, two of which (Cairo DM 138/2 and Dublin 4282/3) bear the title quoted above; a third one (Manchester Rylands 361, ff. 30v–32r) is entitled *Risāla fī 'l-ʿAmal bi-l-rubʿ al-musattar*.

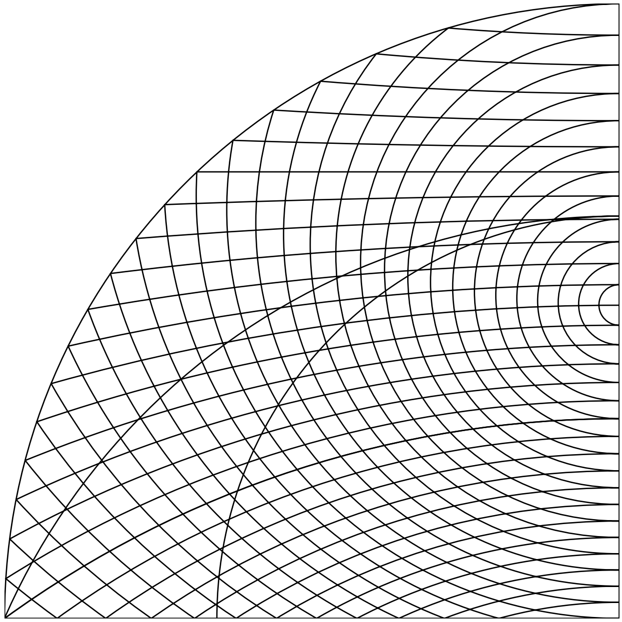

FIG. 2.9. The *musattar* quadrant for latitude 36°

Umayyad Mosque in Damascus al-Tīzīnī (*fl. ca.* 1450) also called this quadrant the *āsa*.[117] The azimuth markings are not represented on the *musattar* quadrant, for otherwise it would be overloaded with lines. Fig. 2.9 illustrates the markings on this instrument, including the inner tropic and the ecliptic, which on both manuscripts are not represented. Najm al-Dīn's instructions for constructing the *musattar* markings (Ch. 55) are not particularly clear, but his procedure nevertheless seems to be sound. The last sentence, however, on the absence of day-circles for inverting the roles of 'north' and 'south', is enigmatic.

2.5 *Horizontal stereographic projection: the* musātira

The two instruments described in Chs. 53 and 54 are based on a stereographic projection onto the plane of the horizon, the nadir being the pole of pro-

[117] al-Tīzīnī's treatise on the use of the *musattar* (whose relation to the one by al-Mizzī mentioned above is not clear, perhaps an abridgement thereof?) is entitled (according to MS Paris 2547/9 – see De Slane 1883):

رسالة مختصرة في العمل بربع الدائرة الموضوع عليه المقنطرات المطوية ويعرف بالآسة والمستّر

For other copies see Brockelmann, *GAL*, II, p. 160.

jection. Such an instrument was called a *musātira* (or perhaps *musātara* ?) in Arabic sources. Mathematically it is closely related to the regular planispheric astrolabe: a *musātira* can be considered as an astrolabe on which the horizontal and equatorial coordinates are interchanged: thus the declination circles are represented on the *musātira* in the same way as the altitude circles on the astrolabe, and the circles of hour-angle in the same way as the azimuth circles. The northern celestial pole is projected in the lower half of the instrument; the markings are restricted to the visible half of the sky, the horizon being the outer limit of the instrument. Since the graduations of the outer rim correspond to the azimuth, this instrument, when properly aligned and fitted with a gnomon at the centre, can also serve as a horizontal azimuthal sundial.[118] Muslim authors considered the *musātira* exclusively as an astrolabic instrument, fitted with a suspensory apparatus and an alidade on the front. In Renaissance Europe, however, the horizontal projection served as the basis for both kinds of instruments.

Whereas the history of the 'horizontal instrument' in Renaissance southern Germany and seventeenth-century England is well documented,[119] there is some confusion in the modern literature concerning its origin and history in Islam. It has wrongly been stated that the *musātira* is equivalent to the 'comprehensive instrument' (*al-ālat al-shāmila*) invented by the tenth-century astronomer from Rayy al-Khujandī, which is in fact an instrument in the shape of a hollow hemisphere fitted with revolving plates.[120] It has very little to do with the *musātira*, apart from the apparent similarity of the *shāmila* with the latter when the hollow hemisphere and its markings are depicted in two dimensions, which probably explains the origin of the confusion. Yet L. A. Sédillot's summary of al-Marrākushī's description of the *musātira* and the

[118] On azimuthal dials, see Section 3.4.

[119] The two major studies are Janin 1979 and A. Turner 1981. See also Gunther 1923, pp. 140–142; Michel 1976, pp. 24, 129–130; A. Turner 1985, pp. 191–195. According to Zinner (1956, p. 163), the earliest occurrence of this instrument in European sources is an illustration in an anonymous manuscript dated 1485; it is not clear, however, whether this really concerns a horizontal stereographic projection. The earliest text on the horizontal instrument (considered as a sundial) is by Georg Hartmann (Nuremberg, 1493–1564), who claimed to have invented it. His treatise in German on its construction and use is extant in an autograph manuscript, and will be published by Reinhard Glasemann as part of a doctoral dissertation at Frankfurt University. The instrument of Philipp Apian called *triens* has exactly the form and purpose of the Islamic *musātira* quadrant (which is in fact one half of a *musātira*). The question whether the instrument could have been transmitted from the Near East to Central Europe cannot be answered fully at the present.

[120] The statement occurs for the first time in Janin & King 1977, p. 199 and again in King 1978a, p. 368, where it is further stated that an example of such a horizontal dial is featured in the last chapter of an Andalusī treatise on mechanics, the *Kitāb al-Asrār fī natāʾij al-afkār* by al-Murādī. The latter is actually an azimuthal sundial of crude design, which has been analysed recently (see Casulleras 1996). (In King 1991, p. 164, and idem 1995, p. 83, however, the instrument is correctly described as being a hemispherical device.) The attribution to al-Khujandī of the invention of the horizontal projection has been repeated by A. Turner (1985, p. 192), probably after the article by Janin & King quoted above, and also in A. Turner 1994, p. 80.

shāmila, though incomplete and confusing, already made it clear that they are two distinct instruments.[121] The fourteenth-century astronomer Ibn al-Shāṭir mentioned the *shāmila* as an example of an ugly instrument.[122] This cannot be said of the *musātira*, which is an elegant application of the principle of stereographic projection.

The term *al-musātira* ("the (instrument) which conceals") – the reading *al-musātara*, "the concealed (instrument)", is also possible – first appears in Arabic scientific literature in a short section of Ibn Yūnus' *Zīj*, presenting a method for determining the meridian with an instrument called a *musātira*.[123] Ibn Yūnus refers here to a simple graduated circle, similar to an Indian circle, on which is mounted an alidade with a perpendicular plate (like the *pinullæ* on the alidade of astrolabes, curiously called a *kursī* by Ibn Yūnus) and placed in the plane of the horizon. In order to perform the operation he advocates there is no necessity for an instrument featuring a stereographic projection and there is no reason to assume that Ibn Yūnus had such an instrument in mind.[124] The first author to discuss the *musātira* in the sense of a horizontal stereographic projection, however, was al-Marrākushī, whose account certainly relies on earlier sources.[125] In fact he presents 4 different varieties of this instrument, defined by two different planes of projection: either the plane of the horizon, or the plane of the local meridian. These two types exist in two versions, 'diurnal' and 'nocturnal': in the first case only declination circles associated with

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[121] Sédillot, *Mémoire*, pp. 148–153. A correct interpretation of the *shāmila* was already given by Josef Frank (1921) in an article published in a relatively obscure German technical journal; his description of the instrument was referred to in Lorch 1980, p. 154, who seems to be the only modern author to have been aware of Frank's article. On al-Khujandī, see Sezgin, *GAS*, VI, pp. 220–222 and S. Tekeli's article in *DSB*. al-Khujandī's treatise on the *shāmila* is extant but has not yet been published. The celebrated twelfth-century astrolabist Hibatallāh al-Baghdādī – on whom see "al-Badīʿ al-Asṭurlābī" in *EI*^{2}, I, p. 858 (by H. Suter) – improved the instrument by making it usable for all latitudes, and wrote a treatise on it, which is also preserved. See Rosenthal 1950, pp. 555-559, and Hopwood 1963, no. 1092.

[122] MS Cairo DM 138/12, f. 35r. The introduction to Ibn al-Shāṭir's treatise on the 'complete quadrant', in which this assertion occurs, is reproduced from MS Damascus Ẓāhiriyya 3098 (nineteenth-century copy of the Cairo MS) in Kennedy & Ghanem 1976, pp. 17–18 of the Arabic section.

[123] This section is edited in Janin & King 1977, pp. 255–256.

[124] The operation described by Ibn Yūnus can be summarised as follows: Compute the azimuth corresponding to a solar altitude which will occur at a later time. Place the alidade vis-à-vis the value on the scale corresponding to that azimuth. Observe the solar altitude until it gets very close to the altitude for which you computed the azimuth. Turn the *musātira* on the horizontal surface until the perpendicular plate of the alidade projects its shadow exactly on the alidade, while the altitude becomes equal to that for which you computed the azimuth. The position of the *musātira* will then yield the cardinal directions.

With a 'stereographic' *musātira* the same operation of finding the cardinal directions becomes much simpler: see al-Marrākushī's *faṣl* 11 of his chapter on the use of the *musātira* [*fann* 3, *bāb* 10, in 23 *faṣl*s] (al-Marrākushī, *Jāmiʿ*, II, pp. 246–256, on p. 251).

[125] al-Marrākushī, *Jāmiʿ*, pp. 21–38 [*fann* 2, *qism* 6, *bāb* 2, in 5 *faṣl*s]; Sédillot, *Mémoire*, pp. 151–153.

zodiacal signs are represented, and in the second case all declinations circles between the equator and the poles are projected. al-Marrākushī included numerical tables to facilitate the construction of the nocturnal and diurnal versions of the horizontal *musātira*; the latter include lines for the seasonal hours and the *ʿaṣr*. The *musātira* resulting from a projection on the meridian is expectedly an instrument fundamentally different from the one considered here, which we can consider as the 'authentic' *musātira*.[126]

The above notes are intended only to provide the reader with a brief overview of the history of the horizontal projection in Islam. A detailed study of al-Marrākushī's presentation would be valuable, together with an investigation of all later sources devoted to this instrument.[127]

2.5.1 *Najm al-Dīn's account*

The same two types of horizontal *musātira*s as in al-Marrākushī's *Jāmiʿ*, namely, the diurnal one for timekeeping with the sun and the nocturnal one for timekeeping with the stars, are featured in Najm al-Dīn's treatise. Versions of both instruments for latitude 36° are illustrated in both manuscripts (complete in **P** but incomplete in **D**); the diurnal *musātira* is shown on Plate 4. On the diurnal variety the declination circles corresponding to each zodiacal sign are represented. Within the interval defined by the solstices the arcs of hour-angle are displayed for each 10°, as well as portions of the concentric circles

[126] By projecting stereographically the horizontal and equatorial coordinate grids of the celestial sphere on the plane of the local meridian, one obtains the same markings as those achieved by a universal projection (see next Section). The 'nocturnal' version of al-Marrākushī's 'meridional *musātira*' is indeed identical to a *zarqālliyya* plate, except that the inclination between the two superposed grids corresponds to the local latitude instead of the obliquity. In the same was it corresponds to the markings of a universal astrolabe on which the position of the rete with respect to the plate is fixed for a particular latitude. Hence this instrument can be used for solving problems in the same way as on the universal astrolabe, but only for one latitude.

[127] I present in the following list all Arabic works on this instrument that are posterior to al-Marrākushī:

- Ibn Samʿūn, *Nihāyat al-musāmara fī 'l-ʿamal bi-l-musātara* (MSS Cairo QM 2/4; Dublin 4833/2);
- Anon., *al-Uṣūl al-thāmira fī 'l-ʿamal bi-rubʿ al-musātira* (MS Cairo QM 2/3);
- Anon., *Risāla al-Musātira* (MS Cairo DM 138/13, ff. 110v–111r);
- Ibn al-Sarrāj, *Risāla fī 'l-ʿAmal bi-rubʿ al-musātira* (one copy in Rampur according to Brockelmann);
- Ibn al-Ghuzūlī, *Risāla fī Kayfiyyat al-ʿamal bi-l-rubʿ al-mansūb li-l-musātira* (MSS Princeton Yahuda 373, ff. 158v–164r; Cairo MM 118);
- al-Karādīsī, *Risāla fī Maʿrifat waḍʿ khayṭ al-musātira wa-waḍʿ khuṭūṭ faḍl al-dāʾir taḥtahu* (Cairo MM 181/1; Cairo TR 343/2);
- The following anonymous note, however, seems unrelated to the horizontal projection (and the above treatise by Karādīsī may likewise be unrelated): *Fāʾida fī Naṣb khayṭ al-musātira* (MSS Cairo Sh 89/3; Princeton 5012 = Yahuda 1116); this text is edited on the basis of the Cairo manuscript in Janin & King 1977, p. 256.

of altitude for each 10°; on Fig. 2.12 the altitude circles are represented completely and for each 3° of argument. On the nocturnal variety (see Fig. 2.13) the declination circles and the circles of hour-angle are completely displayed within the horizon (both for each 10° on the illustration in **P**). Instead of being numbered with the respective values of the declination, in the manuscript the corresponding value of the meridian altitude is inscribed next to the intersection of each declination circle with the meridian line, and for circumpolar declination circles the minimal altitude is also marked next to their northernmost intersection with the meridian. Altitude circles are not represented on the nocturnal version, but in Ch. 53 we are told that their radii can also be marked along the radial scale of an alidade attached at the centre, and this is certainly implicitly assumed in this case.

Najm al-Dīn's procedure for constructing the declination circles is as follows. For each declination circle three points are marked on the plate, corresponding to its intersections with the horizon (i.e., the outer circle) and the meridian. The first two points are marked by means of a table of the rising amplitude. On Fig. 2.10 CD represents the projection of a circle of declination $\delta < 0$. Since the outer circle represents the horizon, points C and D represent the rising and setting points of that declination circle. But by definition the angular distance along the horizon of a rising or setting point from the east or west point is the rising or setting amplitude $\psi(\delta)$, and by virtue of the conformal property of stereographic projection, we also have $EC = WD = \psi(\delta)$. If the declination is positive then C and D will respectively fall in the northern quadrants EN and WN. Thus, if two points C and D are marked on the outer circle at an angular distance from the east and west points corresponding to the rising amplitude, the points of intersection of a declination circle with the horizon can be determined.

The second step consists in counting the corresponding meridian altitude $H(\delta)$ from S along the outer scale SE and to mark it at J; laying the ruler on W and J, one marks its intersection with the meridian NS at Q. The declination circle is then constructed by tracing a circular arc which passes through C, Q and D. Some of the declination circles on the nocturnal *musātira* are circumpolar: they can easily be constructed by marking along the meridian the maximal and minimal altitudes of this declination circle, which will yield two extremities of its diameter; their midpoint will represent its centre. The table in Ch. 54 gives the rising amplitude $\phi(\Delta)$ for arguments $\Delta < 90° - \phi$, and gives h_{max} and h_{min} for the remaining arguments. No comparable table is given in Ch. 53 for $\psi(\delta(\lambda))$.

The next step is to draw the concentric altitude circles. Their radii can be found according to the method given above: placing the ruler on W and J, where arc SJ represents the altitude, its intersection Q with the meridian will give the radius of the corresponding altitude circle.

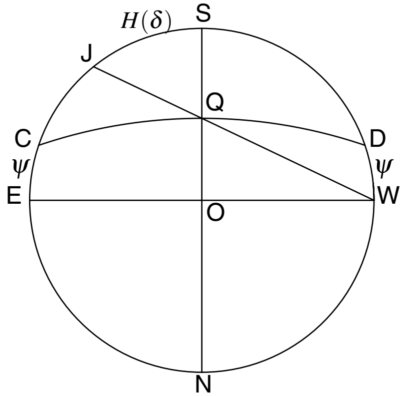

FIG. 2.10. Construction of the declination circles on the *musātira*

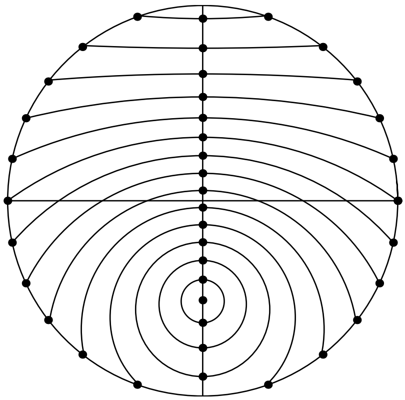

FIG. 2.11. Representation of the construction marks on the nocturnal *musātira* found by means of table T.5

The construction of the arcs of hour-angle in Ch. 53 is as follows. The altitude $h(t,\delta)$ is tabulated for the appropriate range of the hour-angle t at the solstices and equinox. For a given value of t, the intersection of each three declination circles with the altitude circle corresponding to $h(t,\delta)$ will yield three points of the needed arc. In Ch. 54 a different procedure is given which is identical to Najm al-Dīn's procedure for constructing azimuth circles on astrolabe plates (see p. 54 above). The same quantity $h(t)$ (the text has $h(a)$) is now tabulated at the equinox only: these yield a series of marks on the equatorial circle. In order to draw the circles of hour-angle one needs to determine the centre of the circle of hour-angle 90° and to draw a line passing through it which is perpendicular to the meridian. With one leg of the compass on that line, one can find by successive approximations a circle which joins each point marked on the equator with the northern celestial pole.

2.6 *Universal Stereographic Projection*

All the different types of astrolabes discussed up to this point are designed to be used for a specific terrestrial latitude, since the projection of the horizon, altitude and azimuth circles are latitude-dependent. In this section we turn to instruments which are also based on stereographic projection but are universal in their application. The only possible way to achieve astrolabic markings that preserve their properties for all latitudes is to find a special case of stereographic projection for which the horizon will be represented as a straight line going through the centre of the surface of projection. In this way, it would

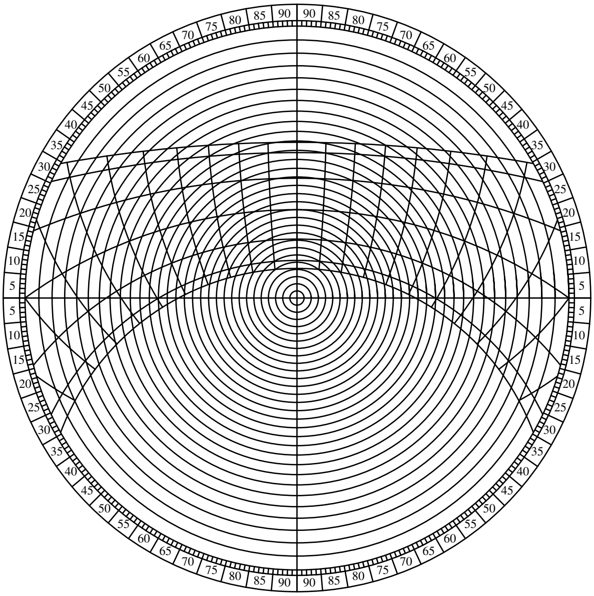

FIG. 2.12. Diurnal *musātira* for latitude 36° (with alt. circles for each 3°)

be possible to adjust the celestial configuration for individual latitudes simply through rotation of the horizon. This can be achieved if the surface of projection is a plane going through the solstitial colures, and if the pole of projection is the intersection of the equatorial and ecliptic circles. On such an astrolabe the configuration of the sky is thus seen 'sideways' instead of 'from above'.

The invention of two distinct but related universal instruments based on that projection are ascribed to the eleventh-century Toledan astronomers ʿAlī ibn Khalaf and his better-known contemporary Ibn al-Zarqālluh (Azarquiel), who in fact devised two different types of universal plates. The morphology and the use of these universal instruments, as well as their historical influence and evolution in East and West, are now well-documented, thanks to the labour of three generations of historians of science in Barcelona. However, the precise historical circumstances of their inventions in al-Andalus are still not clear. In particular, the question whether Ibn al-Zarqālluh or ʿAlī ibn Khalaf should be credited with the priority of its invention has never been resolved.[128] Ibn al-Zarqālluh devised two versions of his universal plate. One variant bore the name *al-ṣafīḥa al-zarqālliyya*, i.e., "the plate of Azarquiel". A second one

[128] Both ʿAlī ibn Khalaf and Ibn al-Zarqālluh claim for themselves the invention of a universal projection.

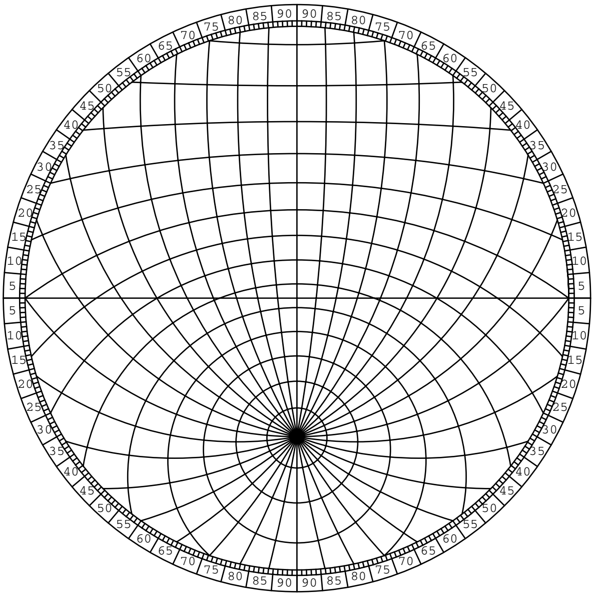

FIG. 2.13. Nocturnal *musātira* for latitude 36°

was called the *shakkāziyya*, presumably by later authors as I shall point out below, but the origins of the term are still obscure. Neither of Ibn al-Zarqālluh's original Arabic treatises on these instruments has yet been published in its original form.[129] A detailed study based on all primary sources dealing with the universal projection and its applications would be welcome, but it is clearly beyond the scope of the present endeavour.[130] Nevertheless, before turning to Najm al-Dīn's descriptions of those universal instruments from al-Andalus – and especially to the new historical information he provides on the rather enigmatic universal astrolabe of ʿAlī ibn Khalaf, it is necessary to present a historiographical introduction to Ibn al-Zarqālluh's works.

[129] This might seem a provocation at this stage, but see my remarks below.

[130] An English translation of ʿAlī ibn Khalaf's treatise – extant in the *Libros del saber* – would also be very useful to historians of instrumentation.

2.6.1 *Historiographical remarks concerning Ibn al-Zarqālluh's universal instruments*

Two versions: the shakkāziyya *and the* zarqālliyya

As already mentioned, Ibn al-Zarqālluh devised two variants of a universal plate based on the universal stereographic projection. This circumstance and the fact that numerous different texts concerning both instruments exist in different languages have led to a major source of confusion for modern historians. In his study on al-Marrākushī, Louis-Amélie Sédillot almost completely ignored the information provided by al-Marrākushī and followed instead the Latin treatise on the *saphea* by Guillelmus Anglicus, of which he edited the part concerning the construction.[131] He stated that the Latin text concerns the *zarqālliyya* and simply noted that the *shakkāziyya*, also described by al-Marrākushī, differed very little from it. In a fundamental bibliographical study on Ibn al-Zarqālluh published between 1881 and 1887, Moritz Steinschneider listed and described all the available manuscript sources related to this author, and he noted the discrepancy between the version preserved in the *Libros del saber* and the translations preserved in Hebrew and Latin, which he could not explain.[132] Some 50 years later José Maria Millás-Vallicrosa recognised that Ibn al-Zarqālluh had written two different editions of his treatise on the 'azafea', one in 100 chapters, which he called "la redacció major", and a second version in 61 chapters ("la redacció menor"), whereby the shorter edition would describe a simpler version of his instrument.[133] The "redacció menor" is the one preserved in the Hebrew and Latin translations,[134] both edited by Millás,[135] who concluded his analysis by assuming that "the universal plate ("assafea") expounded in the second redaction [in 61 chapters] is Azarquiel's definitive and authentic one, even though it corresponds to a simpler, or simplified, type."[136]

[131] Sédillot, *Mémoire*, pp. 183–191, with Latin text on pp. 185–188. This text is not a direct translation of Ibn al-Zarqālluh's original treatise, but rather an independent composition based on it; see Poulle 1970, p. 493.

[132] Steinschneider actually thought that the Castilian translation did not represent the original text, which must have been augmented by paraphrases, interpolations and additions due to later authors. See Steinschneider 1881-87, pp. 343–349 of vol. 18.

[133] Millas 1933, pp. xv–xxvii. Cf. Millás 1943-50, pp. 425–438.

[134] The Latin translation was the result of the collaboration of of Jakob ben Makhir ibn Tibbon (alias Prophatius Judæus) with Johannes of Brescia, as stated in the explicit: "Translatum . . . de arabico in latinum . . . , Profatio gentis hebreorum uulgarizante et Johanne Brixiensi in latinum reducente", Millás 1933, p. 152. The Hebrew translation is in fact anonymous, but Millás attributed it to Jakob ben Makhir in view of its textual correspondence with the Latin translation he was associated with; see Millás 1933, pp. l–li. Steinschneider was more sceptical: see Steinschneider 1881-87, p. 500 of vol. 16 and p. 357 of vol. 18.

[135] Millás 1933, pp. 2–40 (Hebrew), 44–112 (Catalan translation thereof, with notes) and 114–152 (Latin).

[136] Millás 1933, p. xxvii. Cf. Millás 1943-50, p. 437.

In a series of studies on the *shakkāziyya* and *zarqālliyya*, Roser Puig has contributed to the clarification of the morphology of both instruments and their usage.[137] She also published a treatise in 60 chapters attributed to Ibn al-Zarqālluh and preserved in three late manuscripts from the Maghrib, which is simply entitled *al-Shakkāziyya*.[138] She concluded her analysis by correctly stating – albeit only at the very end of the commentary – that the *shakkāziyya* is essentially the instrument described in the so-called "redacción menor" (a hypothesis already formulated 15 years previously by Julio Samsó[139]):

> Finally, the characteristics and the use of this azafea *shakkāziyya* literally coincide with the one expounded in the shorter redaction edited and translated by Millás ... From now on, it is hence possible to identify the treatises on the azafea *zarqālliyya* and the azafea *shakkāziyya*, respectively, with the longer and shorter redactions of the treatise on the azafea which have been established by Millás.[140]

Puig does not clearly state that the *text* of the treatise entitled *al-Shakkāziyya* is *essentially identical* to the treatise in 61 chapters whose Hebrew and Latin translations had been edited by Millás. One reason which might partially explain this oversight is that the Arabic treatise she edited is *not exactly* the original treatise by Ibn al-Zarqālluh. The latter is rather entitled *Risāla fī 'l-ʿAmal bi-l-ṣafīḥa al-mushtaraka bi-jamīʿ al-ʿurūḍ* ("Treatise on the use of the plate common to all latitudes") and contains 61 chapters (we shall henceforth designate it as the *Risāla*). It is extant in relatively many manuscripts, most of which have been listed in the earlier literature.[141] It also contains an in-

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137 See Puig 1985, 1986 and 1987a. Specific aspects of the *zarqālliyya* are also examined in Puig 1989 and 1996. On Ibn al-Zarqālluh's original Arabic treatise on the *zarqālliyya*, see my remarks further below.

138 Puig 1986.

139 Puig 1986, p. 25.

140 Puig 1986, p. 79. Her paper on the *shakkāziyya* published one year previously (Puig 1985) was much more confusing. Following Millás, she had rather presented the instrument described in the version in 61 chapters as a *zarqālliyya*, albeit in a simplified form. She nevertheless concluded her essay by contradicting this with the following enigmatic words: "Furthermore, since the disappearance of the projection on the back is a characteristic of the *ṣafīḥa* described by the so-called simplified treatises, I put forward the hypothesis that the simplified versions are, actually, treatises on the *shakkāziyya*." (Puig 1985, p. 137). The introduction to the edition (Puig 1986) also leaves the impression that the "redacción menor" concerns the *zarqālliyya*, and the reader only learns of the identity between the instruments described in the latter and the *shakkāziyya* treatise at the very end of the commentary.

141 I have consulted microfilms of three manuscripts: Leiden UB Warner 993 (= CCO 1070) (datable *ca*. 700 H), Cairo DH 40 (45 ff., *ca*. 900 H) – both attesting the above title – and also Leiden UB Or. 187B/3 (= CCO 1071) (ff. 63v–82v, copied in *ca*. 950 H). Other copies are Oxford St. John's College 175 and Hamburg Or. 133 (1v-33v). These manuscripts, save the Cairo one, were listed by Steinschneider (1881-87) and Millás (1933) (the Hamburg manuscript was unknown to Steinscheider and was first signaled by Wiedemann & Mittelberger 1926-27). In his notes and in his apparatus of the Hebrew version Millás made frequent references to MS Leiden UB Warner 993.

teresting introduction that is, save for the end, identical to the introduction to the treatise in 100 chapters on the use of the *zarqālliyya*,[142] and in which the author explains his motivation for inventing a universal instrument. This introduction, omitted from the original Hebrew and Latin translations, was however added to the Hebrew translation in the fifteenth century.[143] A German translation of the introduction from the original Arabic was published by E. Wiedemann and T. Mittelberger in the 1920s.[144] The text of the *Risāla* thus corresponds *textually* to the translations published by Millás, a fact he was perfectly aware of.[145] The text published by Puig is virtually the same as that of Ibn al-Zarqālluh's *Risāla* in 61 chapters, with the difference, however, that it lacks the introduction and that the first chapter has been changed into an unnumbered *faṣl*, so that the subsequent numeration of the chapters is reduced by one and reaches 60 instead of 61. The text of this introductory *faṣl* is virtually identical to the first chapter of the *Risāla* up to the last section describing the back of the plate, where both texts suddenly become sensibly different.[146] It is thus indisputable that the treatise *al-Shakkāziyya* edited by Puig from two late Maghribi manuscripts[147] represents a *later recension* of the original work by Ibn al-Zarqālluh, which had a very different title and contained an introduction of considerable interest, the knowledge of which has vanished in recent historiography.[148]

The original Arabic treatises on the zarqālliyya

Some clarification concerning Ibn al-Zarqālluh's treatise on the *zarqālliyya* also seems appropriate. It is now well-known that the *Libros del saber* con-

[142] Rico y Sinobas 1863–66, III, pp. 149–150.

[143] Ibn al-Zarqālluh's prologue was translated by Moshe Galino and is preserved in only one Paris manuscript; see Millás 1933, pp. xlvi and 44. The textual tradition of the Hebrew version is surrounded by the influence of later Jewish scholars, who might have made interpolations and additions to the original text. See also n. 145 below.

[144] See Wiedemann & Mittelberger 1926-27, who based their translation on MSS Leiden UB Warner 993, Leiden UB Or. 187B and Hamburg Or. 133. Recent authors on the topic seem however completely unaware of even the existence of such an introduction by Ibn al-Zarqālluh.

[145] The Hebrew translation presents one trace of contamination from the treatise on the *zarqālliyya* in 100 chapters, but this only concern one passage in the first chapter, which results from a marginal gloss in the Arabic manuscript used by the Jewish translator. The text of the introduction – which as we have seen (n. 143 above) is a fifteenth-century addition – also presents at one place a slight deviation from the Arabic original (of both versions). See Millás 1933, p. 47, n. 2, p. 50, n. 2, and also pp. xlviii and li–lii.

[146] The *Shakkāziyya* text also omits the calendar scale exactly at the place where the two texts start diverging; it is later mentioned as if already known to the reader.

[147] MS Rabat Bibliothèque Royale 6667/2 is dated 1214 H and MS Cairo TR 131/4 (not used by Puig), 1186 H. MS Istanbul University Library A-4800 is undated, but judging from photos (available at the Institut für Geschichte der Naturwissenschaften in Frankfurt), it seems to be posterior to 1000 H.

[148] All this would not have happened had Millás published the original Arabic text, to which he had access, together with its Hebrew and Latin translations.

tain a Castilian translation of Ibn al-Zarqālluh's treatise on the *zarqālliyya*, entitled *Libro de la açafeha*.[149] This consists in fact of two parts: the first part is a treatise in 4 chapters on the construction of the plate; the second part in 100 chapters is on its use. Each part has the form of an independent treatise, and both are preceded by an introduction. In the introduction to the first part we learn that it is dedicated to al-Muʿtamid of Seville (reg. 461–484 H), and this implies it was composed between *ca*. 471 H and 484 H.[150] The original Arabic text of this treatise is extant but is still unpublished.[151] Its original title is *Risāla fī ʿAmal al-ṣafīḥa al-mushtaraka li-jamīʿ al-āfāq wa-l-ʿamal bihā* ("Treatise on the construction and use of the plate common to all horizons").[152] A translation of the second part (excluding the prologue) based on one Arabic manuscript and on the Old Castilian translation was published by Roser Puig in 1987.[153] In earlier publications Puig had claimed that the first part on the construction is not preserved in Arabic. But in a recent article she mentioned that it is preserved in the Paris manuscript.[154] In fact, the first part is also found in the Cairo copy (and perhaps also in the Istanbul copy recorded by Krause). The original version also includes an undated star table, omitted in the Castilian translation, which can be dated to *ca*. 480 H by virtue of the precessional adjustment of the longitudes, a date consistent with the

[149] Rico y Sinobas 1863–66, III, pp. 135–237.

[150] This interval is consistent with the precessional adjustment of the star table included in the original treatise (omitted in the Castilian translation), which suggest a date of *ca*. 480 H (see also n. 155 below). At some point in his life Ibn al-Zarqālluh left troubled Toledo for Córdoba, which from 471 H [= 1078/9] onward had definitively become under the domination of the ruler of Seville. The precise date of his exile is uncertain, but it certainly occurred during the reign of al-Maʾmūn's inept grandson Yaḥyā al-Qādir, who succeeded al-Maʾmūn upon in death in 467 H [= 1074/5], since the biographer Ibn al-ʿAbbār states that Ibn al-Zarqālluh was still active in Toledo under the rule of al-Qādir (see Millás 1943-50, p. 10). In any event his exile certainly took place before Toledo was seized by the Christians in 478 H [= 1085]. For Ibn al-Zarqālluh's biography see Millás 1943-50, pp. 5–6, 13–15; on his patrons and the related historical events in Toledo and Córdova see the articles "Dhu 'l-Nūnids" (by D. M. Dunlop) in *EI*^{2}, II, pp. 242–243 and "al-Muʿtamid ibn ʿAbbād, 1. Life" (by E. Lévi-Provençal), VII, pp. 766–767. The only known dates of Ibn al-Zarqālluh's Cordoban biography concern his dedicating to al-Muʿtamid in 474 H [= 1081/2] a treatise on the equatorium (Millás 1943-50, p. 460), his last observations conducted at the end 480 H [= 1087/8], and finally his death on Friday 8 Dhū 'l-Ḥijja 493 H [= 12 October 1100, not 15 October as stated by Millás] (*ibid.*, p. 10). Millás mentions (p. 15) that Ibn al-Zarqālluh conducted observations in Córdoba prior to 478 H, but does not give any reference to support this claim.

[151] The extant copies are: Paris 4824 (dated?, complete), Cairo DM 647 (*ca*. 600 H, complete), Escorial ár. 962 (undated, perhaps 650 H?, lacking the first part and the prologue of the second one), and Istanbul Esat 3804/3 (665 H, no title given but apparently complete: see Krause 1933, p. 526, listed as anonymous). I have consulted the Cairo and Escorial copies.

[152] This is the title given in the Cairo copy (f. 1r). I do not have access to the Paris copy at the moment.

[153] Puig 1987a. The manuscript she used was Escorial ár. 962: this copy only contains the second part, without the prologue.

[154] Puig 1996, p. 747. See the brief description of the Paris manuscript in Millás 1943-50, p. 429.

dedication to al-Muʿtamid.[155]

There also exists in Istanbul a unique copy of a treatise by Ibn al-Zarqālluh on his *zarqālliyya*,[156] composed in 459 H [= 1066/7] and dedicated to an unnamed ruler, which can only be al-Maʾmūn![157] According to the Alfonsine prologue to the *Libro de la açafeha*, Ibn al-Zarqālluh had indeed dedicated a first version of his plate to al-Maʾmūn. Later he perfected the instrument and wrote a treatise on its use which he now dedicated to al-Muʿtamid.[158] On the title page the title of this treatise is noted (by a somewhat later hand than the copyist) as follows: *Risālat al-Zarqālluh fī ʿamal al-ṣafīḥa al-mansūba ilayhi wa-l-ʿamal bihā* ("Treatise of al-Zarqālluh on the construction and use of the plate named after him").

A preliminary investigation of its contents reveals that this treatise consists of *three* parts, preceded by a prologue: the first part contains a theoretical presentation with proofs of the principle and construction of the *zarqālliyya*; the second part also concerns the construction, but without proofs, and with a more practical intent. Between these is a star table which purports to be for the year 459 H[159] and an inverse shadow table (also found in the *Libros del saber*, III, p. 146). The third part in 80 chapters is on the use of the instrument: practically all of its contents are textually reproduced in the treatise in 100 chapters dedicated to al-Muʿtamid. The latter version is thus obviously a slight rearrangement and expansion of the earlier version in 80 chapters. It could well be the *maʾmūniyya* version of the instrument, mentioned in the introduction to the Alfonsine translation, whilst the expanded treatise in 100 chapters would correspond to the improved *ʿabbādiyya* version.[160] Now, a quotation of Ṣāʿid al-Andalusī[161] in an anonymous early fourteenth-century treatise on *mīqāt*, reports that Ibn al-Zarqālluh "invented the *zarqālliyya* [MS: *al-zarqālla*] and wrote (a treatise in) 100 chapters on its use, around the year 440 H [= 1048/9]".[162] Except for the data concerning the number of chapters,

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[155] The longitudes are augmented in average by 14′ over an otherwise identical star table dated 459 H, included in Ibn al-Zarqālluh's treatise on the standard astrolabe and also in several copies the *Toledan Tables* (see Kunitzsch 1980, pp. 196–197). Using Ibn al-Zarqālluh's third precession model (see Mancha 1998), I found that this increment corresponds to a time span of 21 lunar years over the first table.

[156] MS Istanbul Aya Sofya 2671, ff. 1r–75r. See Krause 1936, p. 482. It is important to mention in passing that Ḥājjī Khalīfa (*Kashf al-ẓunūn*, I, col. 1441) falsely attributes a treatise on the *zarqālliyya* to al-Khujandī, who lived in Rayy in the tenth century.

[157] This was already noted in King 1979a, p. 253.

[158] Rico y Sinobas 1863–66, III, p. 135.

[159] See the edition and comments in Kunitzsch 1980.

[160] See Rico y Sinobas 1863–66, III, p. 135 and Millás 1943-50, p. 13.

[161] On whom see EI^2, VIII, pp. 867–868.

[162] King 1979a, p. 252. This quotation has been interpreted to mean that Ibn al-Zarqālluh had dedicated the treatise in 100 chapters to al-Muʿtamid already in 440 H, when the future ruler of Seville was only eight or nine years old (Samsó 1994b, p. 10). This is historically impossible since in those years Ibn al-Zarqālluh enjoyed in Toledo the patronage of al-Maʾmūn, whose rivalry

which might result from a later interpolation, Ṣāʿid's information is consistent with the discussion above. Yet it is certainly too early at this stage to make any more pronouncements on the history of Ibn al-Zarqālluh's writings on the *zarqālliyya*. The new material available in the Istanbul manuscript deserves publication and analysis, as do the original Arabic versions of his other two better-known treatises.

2.6.2 *The* shakkāziyya *plate*

The outer rim of the plate is the meridian circle, the vertical diameter represents the equator, and the horizontal diameter coincides with the line joining the northern and southern celestial poles. The circles of declination and the meridians are projected from the vernal or autumnal point onto the plane of the solstitial colure. In this plane, the ecliptic will project as a straight line, and it is represented on the plate as a diameter inclined to the equator by the amount of the obliquity, with its superior extremity in the upper right quadrant. The great circles of longitude delimiting the zodiacal signs are also represented. Finally, a graduated alidade is fitted on the front, which serves as a movable horizon. Of course the markings on the plate representing the equatorial coordinate grid can also be considered to represent horizontal or ecliptical coordinates, and this is an essential feature of the instrument.

The origin of the term shakkāziyya

Since the term *shakkāziyya* does not appear in Ibn al-Zarqālluh's original work, one is led to ask when it originated. Even though it cannot be associated directly with Ibn al-Zarqālluh or his treatise, the epithet *shakkāziyya*, which serves to identify one type of universal plate in later sources (the first occurrence is in al-Marrākushī), must have been coined much earlier, perhaps even during Ibn al-Zarqālluh's lifetime or by his immediate successors.

Julio Samsó has shown that the term *shakkāz* (meaning "tanner, bleacher of hides") refers to a quarter of Toledo where people exercising that trade lived.[163] Andalusī writers on Ibn al-Zarqālluh's universal plate must have been confronted with exactly the same problem which has plagued modern authors for more than a century and a half: how to distinguish the two versions of Ibn al-Zarqālluh's instrument. Since one instrument was simply named *zarqālliyya* after its author, it was rather natural to find another epithet for the second instrument. If *shakkāz* indeed refers to Toledo, this would indicate that the instrument was invented by Ibn al-Zarqālluh while he lived there, that is, probably before his 'exile' to Cordoba *ca.* 470 H. Since it is now certain that the *zarqālliyya* was invented in Toledo before 459 H, could we perhaps assume that the *shakkāziyya* – which is a simplification but not really

with the ʿAbbādids of Seville is well documented.

[163] Samsó 1972, p. 187.

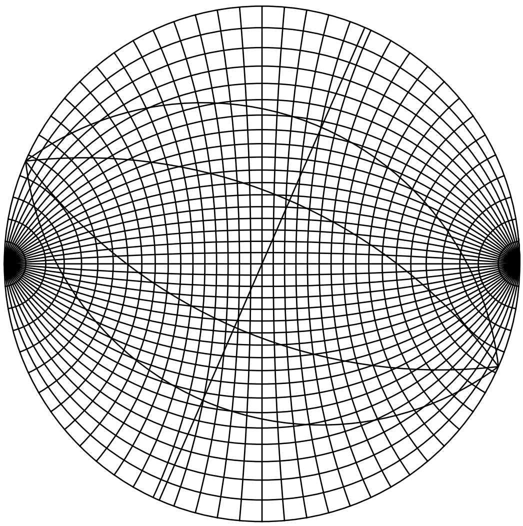

FIG. 2.14. Ibn al-Zarqālluh's *shakkāziyya* plate

an improvement over the *zarqālliyya*– was also devised in Toledo during the period *ca*. 460–470 H?

It has also been suggested that the name *shakkāziyya* might be a corruption of *shajjāriyya*, after Abū al-Shajjār, as ʿAlī ibn Khalaf was also named.[164] But Najm al-Dīn, as we shall see, calls ʿAlī ibn Khalaf's instrument the *shajjāriyya*, which seems to indicate that both terms existed in parallel.

2.6.3 *The* zarqālliyya *plate*

The front of the *zarqālliyya* plate bears a superposition of equatorial and ecliptic coordinate grids, equivalent to two sets of universal (*shakkāziyya*) markings at an angle equal to the obliquity of the ecliptic (see Fig. 2.15). This overlapping of two dense networks of curves makes the practical use of the instrument totally confusing, but it facilitates the conversion of coordinates between the equatorial and ecliptic reference frames. The *zarqālliyya* plate features several important improvements over the simpler *shakkāziyya*. The alidade on the front is now fitted with a perpendicular ruler which facilitates the transposition from one coordinate system to another by a simple rotation of the alidade. The back is characterised by two major innovations, unrelated to the universal stereographic projection, which should be considered

[164] See note 178 below.

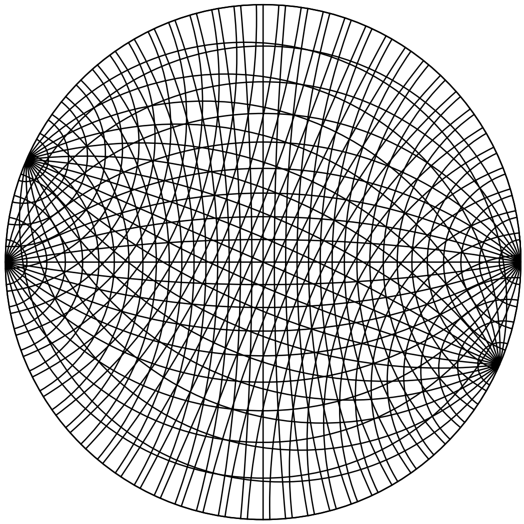

FIG. 2.15. Ibn al-Zarqālluh's *zarqālliyya* plate

as independent devices. An orthogonal projection of the equatorial coordinate system in the plane of the colures occupies three of four quadrants in the central area: this is the first application of the orthogonal projection – whose principle had been described by al-Bīrūnī for an astrolabe of the standard variety – to a universal instrument. In Renaissance Europe the idea was again applied, although with a different design strictly aimed at timekeeping with the sun, to the instrument called *organum Ptolemæi*, probably invented by Regiomontanus, and later to the astrolabe of Helt and De Rojas.[165] The morphology, construction and use of this orthogonal projection have been investigated for the first time in recent years by Roser Puig.[166] The back of the instrument also features a small circle called "circle of the moon": this is a

[165] On the *organum Ptolemæi*, see Zinner 1956, pp. 131–134. The earliest instrument featuring an *organum Ptolemæi*, an astrolabe made by Regiomontanus in 1462, is described in *Focus Behaim Globus*, II, pp. 586–589, and King & Turner 1994. On the astrolabe of Helt and De Rojas, see Michel 1976, pp. 20, 103–109, and Maddison 1966. The *organum Ptolemæi* was until recently completely neglected in the modern historiography of instrumentation, and its equivalence with the astrolabe of Helt and De Rojas is never mentioned! An Iranian astrolabe dated 1094 H [= 1683] with an *organum Ptolemæi* engraved on one of the plates – unmistakably after a European model – is briefly described in King 1999, p. 320, where the orthogonal projection of Ibn al-Zarqālluh is, however, not mentioned (see also *ibid.*, p. 321, n. 134 on an Indo-Iranian instrument with orthogonal projection). See further King, "Universal Horary Dials".

[166] Puig 1987a, 1987b and 1996. Puig traces back the theory underlying Ibn al-Zarqālluh's orthogonal projection to writings of al-Bīrūnī; I would nevertheless consider an independent invention in al-Andalus equally possible.

simple but clever graphical device for finding lunar distances.[167]

The *zarqālliyya*, although a more refined instrument, had less success than the *shakkāziyya*.[168] The Maghribi mathematician Ibn al-Bannāʾ wrote on its use,[169] and al-Marrākushī composed a recension in 130 chapters of the original treatise, which he included in his *Jāmiʿ*.[170] Ibn al-ʿAṭṭār mentioned the *zarqālliyya* in his survey of quadrants, describing its markings in general terms after al-Marrākushī; he omitted to explain its construction "because people of our climate in recent times had no inclination to make it", and added that it is only made in Persia and the Maghrib.[171] Examples made in the Maghrib are well-documented, but the statement concerning Persia is totally surprising, for no example of *zarqālliyya*, let alone of *shakkāziyya*, is attested on astrolabes of Iranian provenance. There are, however, two spectacular examples of *zarqālliyya*s made in India.[172]

One final note: I have noticed that in Near Eastern manuscripts from the Mamluk and Ottoman periods, and in particular in both copies of Najm al-Dīn's treatise, the instrument under discussion is almost constantly spelled الزرقالة, which indicates that the adjective *zarqālliyya* accompanying the word *al-ṣafīḥa* has become a substantive on its own.[173]

2.6.4 *ʿAlī ibn Khalaf's universal astrolabe*

The universal astrolabe of ʿAlī ibn Khalaf[174] is composed of a *shakkāziyya* plate representing the horizontal coordinates, with the zenith-nadir axis represented as the vertical diameter; alternatively this grid is used to represent

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[167] See Puig 1989.

[168] The front of the *zarqālliyya* was described by Guillelmus Anglicus in 1231 (see Poulle 1970, pp. 497–498), but it did not attract any attention thereafter. Poulle claims that Guillelmus described an instrument he only knew "par ouï-dire ..., sans avoir vu ni instrument arabe, ni texte dont il n'existait pas encore, en 1231, de traduction occidentale" (*ibid.*, p. 497). I have, however, some difficulty accepting this, and the question of Guillelmus' sources definitively deserves further investigation.

[169] Puig 1987c.

[170] al-Marrākushī, *Jāmiʿ*, II, pp. 293–336 [*fann* 3, *bāb* 12]; this was not mentioned by Sédillot. This treatise is also found independently in MS Leipzig Universitätsbibliothek 800 (anonymous): see Millás 1943-50, pp. 447–448, and King 1979a, p. 253, n. 21. There is also an abridgement thereof in 26 *faṣl*s in MS Paris 2547/10. al-Marrākushī says in his introduction that he has written another treatise on the use of the *zarqālliyya* "with proof", which is *perhaps* extant in MS Istanbul Hamidiye 874, ff. 59–64 (see Sezgin's preface to al-Marrākushī, *Jāmiʿ*, p. ii).

[171] MS Vatican Borg. 105, f. 6v:18-19.

[172] See Sarma 1996, containing a description of a *zarqālliyya* made in Delhi by Ḍiyāʾ al-Dīn in 1091 H [= 1680/1], and measuring 55.5 cm in diameter. A second, undated (but later than the previous one) and anonymous example of an Indian *zarqālliyya* of 92 cm in diameter was offered in auction in 1992 (Christie's, London, 24 September 1992, lot 119).

[173] Cf. King 1979a, p. 248 and p. 255, n. 2.

[174] On ʿAlī ibn Khalaf and the Alfonsine treatise on the *laminá universal*, see Millás 1943-50, pp. 438–447.

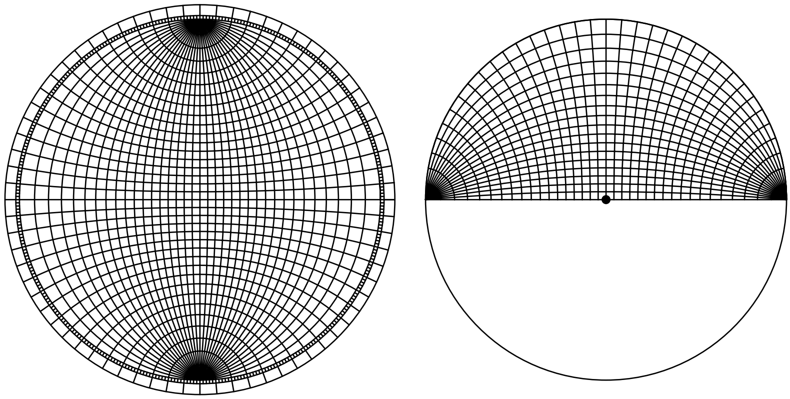

FIG. 2.16. ʿAlī ibn Khalaf's universal astrolabe (plate and upper half of the rete – the lower half carries star-pointers only)

ecliptic coordinates.[175] This plate is fitted with a movable rete, half of which bears various star-pointers. The positions of the star-pointers are defined according to the same projection as that of the plate, that is, exactly as on the *shakkāẓiyya* and *zarqālliyya* plates.[176] The other half is composed of a *shakkāẓiyya* grid pierced out in the sheet of metal; this grid represents equatorial coordinates, with the poles located on each side of the diameter separating the two halves (see Fig. 2.16). The universal astrolabe is hence a device superior to Ibn al-Zarqālluh's *shakkāẓiyya* or *zarqālliyya* plates, since it can represent, for any latitude, the celestial configuration with respect to two coordinate grids, instead of just one. This makes it possible to solve any of the standard problems of spherical astronomy, in particular the time and azimuth as a function of solar (or stellar) altitude, in a direct way, whereas the same problems can only be solved approximately (or by successive approximations) with the *shakkāẓiyya* plate.

The version of Najm al-Dīn

Najm al-Dīn's description of ʿAlī ibn Khalaf's astrolabe is the only extant source in Arabic on this important instrument from eleventh-century al-Anda-

[175] On the universal astrolabe of ʿAlī ibn Khalaf, see North 1976, II, pp. 189–190, and Calvo 1990.

[176] This is clear from the first chapter of Book 4 on finding the longitude and latitude of the stars on the rete: see Rico y Sinobas 1863–66, III, p. 92. North rather interpreted the star-pointers as being according to the projection of a standard astrolabe: "The other half of the rete carries star-pointers in such a way that the plate can be used as a conventional plate of horizons" (North 1976, II, p. 189). The statement by Puig (1992, p. 69) that "la segunda mitad indica las estrellas fijas de una manera similar al astrolabio" suggests the same interpretation.

lus. The original treatise by ʿAlī ibn Khalaf on the use of his instrument is preserved only in Castilian translation in the *Libros del saber*, where the instrument is called a *lámina universal* or *orizon universal*.[177] Oddly enough, Najm al-Dīn qualifies it a "Byzantine" (*rūmī*) astrolabe, and he adds that it is also called *al-shajjāriyya*. The latter epithet refers unequivocally to the person of ʿAlī ibn Khalaf, who was also known as Abū al-Shajjār (or Ibn al-Shajjār), as David King has demonstrated.[178] Whilst Najm al-Dīn provides this new evidence for linking the name Shajjār with ʿAlī ibn Khalaf, his systematic parallel use of the terms *shakkāziyya* and *shajjāriyya* to designate two distinct instruments renders the hypothesis that the former word might have originated as a corruption of the latter highly questionable (see above). It seems in fact more likely to assume that both terms existed in parallel, although one may have been created as a pun on the other, already existing name.

The problem of the ecliptic belt and star-pointers. While one half of the rete illustrated in Najm al-Dīn's treatise bears the same half-*shakkāziyya* grid as on ʿAlī ibn Khalaf's original astrolabe, the other half carries, in addition to the star-pointers, a 'half myrtle ecliptic' with double graduation (see Fig. 2.17 and Plate 5); such an ecliptic is *not* featured on ʿAlī ibn Khalaf's instrument.[179] This ecliptic belt is in fact almost identical to the one on Ibn al-Sarrāj's universal astrolabe (see Fig. 2.18): on Najm al-Dīn's version it results from folding the upper half of a myrtle ecliptic belt (see Section 2.3.3) carrying the southern signs, on its lower half, whilst on Ibn al-Sarrāj's astrolabe the arrangement of the signs result from a 180° rotation of one half to coincide with the other half.[180] Also, the positions of the star-pointers are defined in the same manner as on Ibn al-Sarrāj's astrolabe, namely, according to a standard stereographic projection on the plane of the equator from either the northern or the southern pole (in other words, according to the same projection that defines the

[177] It is important to emphasise that ʿAlī ibn Khalaf's instrument is *more* than just a *lámina*; it is rather an *astrolabio universal*. But this is, of course, modern terminology: in any case, ʿAlī ibn Khalaf's dual terminology (perhaps from the Arabic *al-ṣafīḥa al-āfāqiyya*?) strictly refers to the plate bearing a horizontal coordinate grid, the rete being called "la red de la lamina".

[178] King 1979a, pp. 250–252. The evidence presented by King can be summarised as follows: (1) In a colophon of a copy of Ibn al-Zarqālluh's treatise on the *zarqālliyya* in 100 chapters it is stated (in a later hand, though) that Ibn al-Zarqālluh made his plate after Abū al-Shajjār had made his own plate – similar to Ibn al-Zarqālluh's first plate – which was provided with a rete. (2) In the *zīj* of Ibn Isḥaq we learn of the existence of one ʿAlī al-Shajjār who conducted observations in Toledo in 477 H. (3) An anonymous early fourteenth-century Egyptian treatise on timekeeping quotes Sāʿid al-Andalusī who reports that Abū 'l-Ḥasan ʿAlī ibn Khalaf ibn Akhyr [= Aḥmar ?] known as al-Sḥ'wy [السحاوي] had made a universal astrolabe in 464 H for al-Maʾmūn of Toledo, and that Ibn al-Zarqālluh had invented his *zarqālliyya* around 440 H. Sḥ'wy is possibly a corruption of Shajjār [سحاوي < شجاري].

[179] *Contra* King 1979a, p. 246 and Moreno, Van Cleempoel & King 2002.

[180] For practical uses, Ibn al-Sarrāj's arrangement is more convenient, since it preserves the natural anticlockwise ordering of the signs as on a standard astrolabe.

ecliptic). Such a configuration bears no relation to the star-pointers on ʿAlī ibn Khalaf astrolabe.

The question we are immediately led to ask is: where did Najm al-Dīn get the idea? A straightforward answer may simply be that he added to ʿAlī ibn Khalaf's instrument the ecliptic belt introduced by Ibn al-Sarrāj on his own version of the universal astrolabe, which he had certainly devised *before* Najm al-Dīn composed his instrument treatise.[181] How, then, to explain the complete silence of Najm al-Dīn on the achievements of his contemporary colleague? The fact that the ecliptic belt appears as a standard feature of Najm al-Dīn's *shajjāriyya* raises the suspicion that it could have already been associated with ʿAlī ibn Khalaf's universal astrolabe long before. Could ʿAlī ibn Khalaf himself have added it to his astrolabe at a later stage, not reflected in the Alfonsine version? Or perhaps was it a modification introduced by successors? This hypothesis receives considerable weight by considering the following facts: The rete of the *lámina universal* described in an anonymous *Latin* translation or adaptation (made in London in 1147 AD, probably by Abraham ben Ezra) of an unknown *Arabic* treatise, *apparently bears an ecliptic*![182] Is is also of considerable interest that the French astronomer Jean de Lignères (early fourteenth century) fitted his *saphea* with a movable part, which he called *circulus mobilis*, characterised by a semicircular frame with a doubly graduated half-myrtle ecliptic inside, identical to the ecliptic on Ibn al-Sarrāj's instrument.[183] Also, a contemporary of Jean de Lignères and Najm al-Dīn, the Moroccan ʿAlī ibn Ibrāhīm al-Jazzār made in 728 H [= 1327/8] an astrolabe with the universal plate of Ibn Bāṣo (see next Section) engraved in the mater (but bounded by the equator), and fitted with a complete myrtle rete (see p. 73 above).[184] But this instrument may not necessarily be of any

[181] Ibn al-Sarrāj's elaborate compound astrolabe preserved in the Benaki Museum, Athens, and dated 729 H, represents the culmination of a development which must have taken place within at least one or two decades. Ibn al-Sarrāj's treatise on a simpler version of the astrolabe must have been well-known to specialists in Egypt and Syria already before the much more complex Benaki astrolabe was built. On Ibn al-Sarrāj's universal astrolabe, see the overview in King 1987c; an exhaustive study (King & Charette, *Universal Astrolabe*) is in preparation.

[182] This treatise, preserved in the unique manuscript Oxford, Digby 40, describes in six chapters the construction of the instrument; see the summary in North 1976, III, pp. 162–164. According to North, the last chapters describe the construction of "the rete ..., the stars on the rete, and finally the zodiac" (*ibid.*, p. 162), which indeed seems to imply that the zodiac is on the rete, although North later explicitly states (p. 164) that the rete described in the text is identical to that of ʿAlī ibn Khalaf.

There is an unstudied Latin text preserved in MS Wolfenbüttel Aug. Qu. 24, which according to Steinschneider represents an abbreviated version of ʿAlī ibn Khalaf's treatise (either based on the Castilian translation or on an Arabic original different from the one on which the latter is based). See Steinschneider 1881-85, pp. 583–584 of vol. 20. I am not aware of any mention of this treatise in the secondary literature since Steinscheider.

[183] Poulle 1970, pp. 499–500. This design was also known to some Renaissance astronomers, including Regiomontanus (by means of an anonymous treatise): see *ibid.*, pp. 506–507.

[184] On this instrument, see North 1976, II, pp. 190, and Calvo 1990, pp. 223–225.

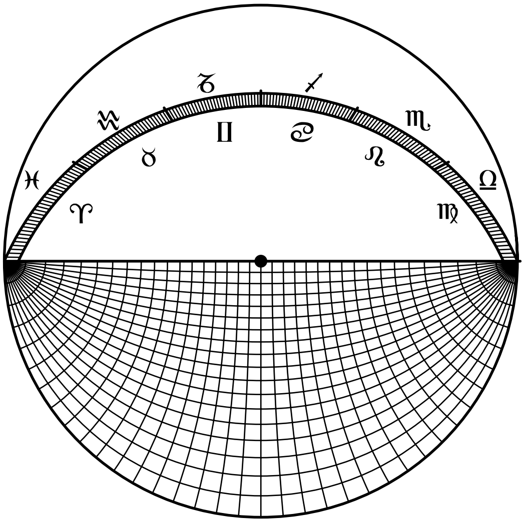

FIG. 2.17. The rete with half-myrtle ecliptic on Najm al-Dīn's version

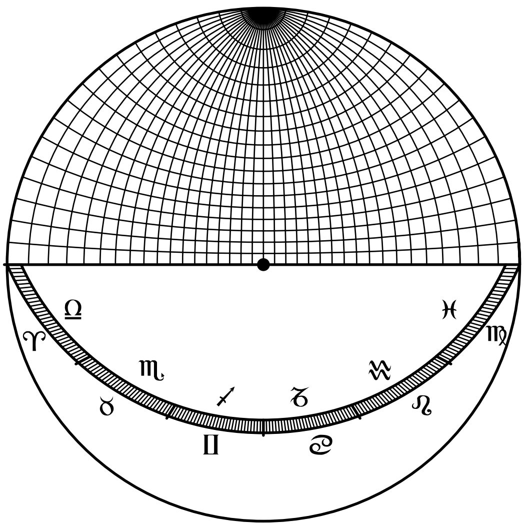

FIG. 2.18. The rete of Ibn al-Sarrāj's universal astrolabe

significance in the present context, since it can be explained as an adaptation of Ibn Bāṣo's plate, which is not directly related to ʿAlī ibn Khalaf's *laminá universal*.

2.6.5 *Ibn Bāṣo's universal plate*

A further development occurred in Granada two centuries after ʿAlī ibn Khalaf and Ibn al-Zarqālluh. Abū ʿAlī al-Ḥusayn Ibn Bāṣo (d. 716 [= 1316]) devised a universal plate which is, morphologically, at once an extension of the traditional plate of horizons and of the *shakkāziyya*.[185]

The universal plate bears the three usual declination circles of a standard plate in northern projection (Cancer, equator and Capricorn). A set of complete horizons (*āfāq*) is represented on this plate for the full range of latitudes 0–90° (and with their 'natural' orientation, as opposed to the 'plate of horizons'). Also represented are concentric declination circles (*madārāt*), equivalent to the projection of altitude circles for a latitude of 90°. The third set of markings (called *qisī*, "arcs") corresponds to the projection of small circles parallel to the meridian, and getting smaller and smaller as they approach the east and west points. All these markings fill the complete surface of the plate in the upper half, but in the lower half they are not traced outside the equator. The result is shown in Fig. 2.19a. When seen 'sideways', the horizons and the 'arcs' are equivalent to twice the markings (on both sides) of a plate for latitude zero, which in turn is also identical – for the region within the equator – to the meridians and parallels of a universal projection.

Ibn Bāṣo's universal plate is intended as a supplementary plate for a standard astrolabe; it is frequently featured on Maghribi astrolabes made until the eighteenth century, and it is also found on one Moghul astrolabe.[186] This plate serves the solution of all problems of spherical astronomy for all latitudes in an elegant and very flexible fashion, explained in detail in a lengthy treatise by Ibn Bāṣo.[187]

Najm al-Dīn informs us that he discovered this instrument (in fact a slight variant thereof) independently in the year 723 H [= 1323/4] at Mecca.[188] Back in Cairo, Najm al-Dīn saw an instrument of brass of *maghribī* style "attributed to the *shaykh* Ibrāhīm ibn ʿAlī ibn Bāṣo al-Andalusī".[189] He also mentions that he has obtained a copy of a treatise on the use of Ibn Bāṣo's plate.

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[185] On Ibn Bāṣo, see the introduction to Calvo 1993.

[186] See Calvo 1993, p. 28.

[187] Calvo 1993 contains the edition of Ibn Bāṣo's treatise with translation and commentary.

[188] The text has Bakka, which is an alternative name of Mecca, mentioned in Qurʾān III, 90.

[189] This name, although it is not found in the bibliographical sources, must refer to a relative of Abū ʿAlī al-Ḥusayn ibn Bāṣo, the inventor of the universal plate in question. Three astrolabes signed Aḥmad ibn Ḥusayn ibn Bāṣo and dated between 694 and 709 H are preserved in various collections (King, *Frankfurt Catalogue*, Section 1.6).

Najm al-Dīn's universal plate (Ch. 10) is basically the same as that of Ibn Bāṣo, except that the markings are now oriented vertically (see Fig. 2.19b), a modification of little practical consequence: it makes the use of the plate easier when it is considered as an extended *shakkāziyya*; but when the meridians are used as horizons, they have to be seen sideways. In Ch. 43, Najm al-Dīn presents a version of this plate reduced to a quadrant.

2.6.6 *Najm al-Dīn's method of constructing universal plates*

Najm al-Dīn constructs the markings of a universal projection with the simple and well-known geometrical method, described with almost the same words in Chs. 9, 29, 39, 40 and 41.[190] At the outset he informs his reader that no table is necessary in distinction to the construction of astrolabes for specific latitudes, because of the identity $T(\phi = 0, \delta = 0, h) = h$, which simply means that on an astrolabic plate for latitude 0°, the angular coordinate (measured from the east and west points) of the intersection of an altitude circle with the equator will be given by the argument h of that altitude circle. For this reason such a table was left out. This kind of argumentation justifying the omission of a table compiled from the *Jadāwil al-Dāʾir* in trivial cases occurs frequently in the treatise, and appears to fulfil a purely rhetorical purpose.

The geometrical construction is simple: one lays a ruler on one extremity of the horizontal diameter and at the graduation on the scale of the opposite quadrants corresponding to the desired arguments, and marks its intersection with the vertical diameter, on both sides. The same operation is also made with the horizontal diameter. The circular arcs passing through each of those marks and whose extremities are the associated graduations of the outer circle will represent the parallels (called *al-muqanṭarāt* in the text, because they are equivalent to altitude circles for latitude 0°). For the meridians (or "azimuths"), one draws circular arcs centred on the horizontal diameter (or its extension) and passing through both extremities of the horizontal diameter and through each mark made on this diameter.

In addition, Chs. 39 and 40 include numerical tables that give the distance from the centre of the plate of each mark to be made on the diameters, and these are of course equivalent to the radii of declination circles. In Ch. 39 the radius of the equator is assumed to measure 30^p, and the radii are given for each 5° of argument. The table in the following chapter assumes a radius of the equator of $19;39^p$, corresponding to a standard astrolabe with outer radius 30^p. Although the text does not say so, this table is thus designed to assist in the construction of the plate of Ibn Bāṣo, or of an astrolabe plate for latitude 0°.

[190] For a more detailed treatment see Michel 1976, pp. 95–97. An erroneous construction in the *Libros del saber* is presented in Samsó 1987.

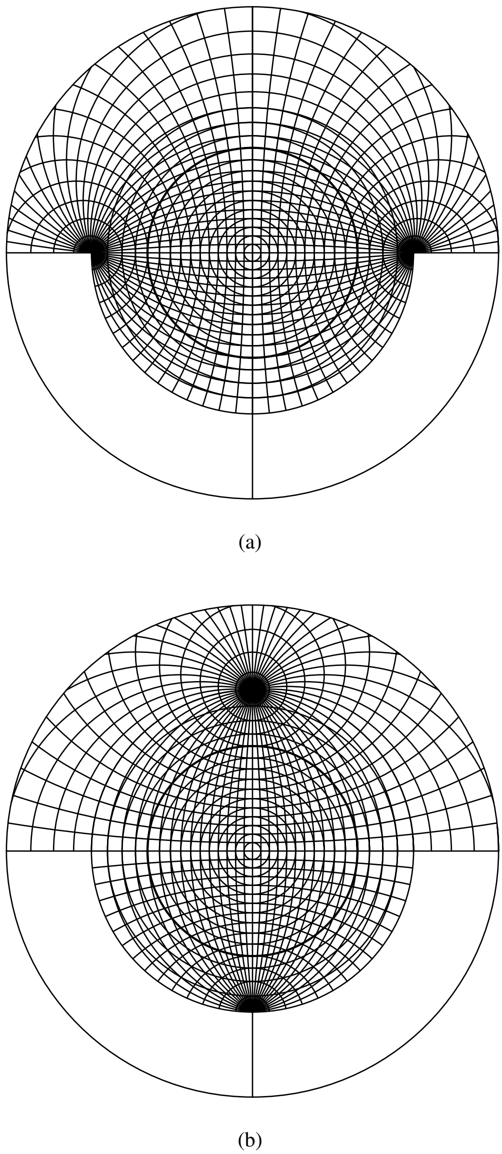

FIG. 2.19. Ibn Bāṣo's universal plate (a)
and Najm al-Dīn's version thereof (b)

The construction of Ibn Bāṣo's plate (Chs. 10, 43) also does not present any difficulty, since it is equivalent to a *shakkāziyya* plate whose markings are extended to the circle of Capricorn: this makes them identical to a standard plate for latitude zero. The concentric circles, representing altitude circles for latitude 90°, are also equivalent to declination circles. Their radii are easily given by the intersections of the meridians ('azimuths' in Najm al-Dīn's terminology, corresponding to the horizons on Ibn Bāṣo's plate) with the east-west line. These concentric circles are not mentioned in Ch. 10, although they are illustrated in **P**.

2.6.7 *The quadrant versions of the universal plates*

The quadrants versions of universal instruments present no difficulty, as they display the same markings restricted on one quadrant. al-Marrākushī mentions a quadrant version of the *zarqālliyya* that features the orthogonal projection on the back together with a movable cursor bearing a calendar scale.[191] He calls it the "sine face" (*al-wajh al-jaybī*), but its use is not yet clear.[192] Najm al-Dīn discusses only the front of this instrument (Ch. 41). In Ch. 40, Najm al-Dīn provides one of the earliest descriptions of the *shakkāzī* quadrant, an instrument which became suddenly popular in the fourteenth century as an abstract trigonometric grid, and we shall discuss it further in Section 5.4.[193] In the introduction to his treatise on the use of this instrument, Ṭaybughā al-Baklamishī seems to imply that he was its inventor,[194] and the Ottoman bibliographer Ḥājjī Khalīfa explicitly credits him with its invention.[195] This information was repeated by a seventeenth-century Egyptian author, Abū al-Fatḥ ibn ʿAbd al-Raḥmān al-Danūsharī.[196] The attribution is, however, highly doubtful since Ibn al-Sarrāj, who lived several decades before al-Baklamishī, knew this instrument perfectly well and also devoted a treatise to its use.[197] Ibn al-Shāṭir also wrote on a variant of the *shakkāzī* quadrant before 733 H [=

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191 al-Marrākushī, *Jāmiʿ*, I, pp. 375:12–377:1. Cf. Sédillot, *Mémoire*, pp. 104–106.

192 See the remarks in King, *SATMI*, VIIa, § 8.3.

193 Here is a list of all Mamluk authors on the *shakkāzī* quadrant – unless otherwise indicated their treatises are extant; those mentioned by Ḥājjī Khalīfa (*Kashf al-ẓunūn*, I, col. 866–870) are marked with an asterisk: Ibn al-Sarrāj (his treatise on its use is lost, but the instrument is described in another work, which is extant), Shihāb al-Dīn al-Bakhāniqī, Ibn al-Shāṭir (only one treatise on a variant of the instrument is extant, but not those on the *shakkāzī* quadrant), Ṭaybughā al-Baklamishī (*), ʿAlī ibn Ṭaybughā, al-Wafāʾī, al-Tīzīnī, al-Shādhīlī (*), and Taqī al-Dīn, surnamed Abū Ṭāhir (*).

194 MS Princeton Yahuda 373, f. 149v.

195 Ḥājjī Khalīfa, *Kashf al-ẓunūn*, I, col. 866–867.

196 See Samsó & Catalá 1971, p. 11. There is also a quotation of the corresponding passage of Ḥājjī Khalīfa in MS Princeton Yahuda 373, f. 149r.

197 Samsó & Catalá 1971 and King 1988, p. 163, did not question Ḥājjī Khalīfa's statement.

1332/3].[198]

Finally we mention the double *shakkāzī* quadrant, which is the quadrant version of the universal astrolabe, consisting of a standard *shakkāzī* quadrant over which rotates another *shakkāzī* grid carved out of a metallic or wooden plate, exactly on the universal astrolabe. Jamāl al-Dīn al-Māridīnī composed a treatise on its use.[199]

[198] His treatise on the "universal quadrant" *al-rubʿ al-jāmiʿ*, composed before 733 H, describes a *shakkāzī* quadrant deprived of its meridians: see MS Oxford Bodleian Selden sup. 61/2, ff. 70r–91v, copied 733 H. In the first part of the same manuscript (f. 64r, dated 773 H), Ibn al-Shāṭir says that he has written two treatises on the *shakkāziyya*.

[199] See King 1974.

CHAPTER THREE

HORARY QUADRANTS AND PORTABLE DIALS

Horary quadrants and portable dials of various shapes form a category of instruments for which early textual sources are scarce. Only a few short texts describing such devices, most of them unpublished, are known from the period *ca.* 800–1200 AD. I shall mention these texts, as far as they are known to me, in this chapter. Until now the best account on the morphology and use of the standard varieties of such instruments remains that of al-Marrākushī. The richest source of information, however, is undoubtedly found in Najm al-Dīn's treatise, which is remarkable for the number and originality of the various horary instruments it features, most of them being otherwise unrecorded.

All instruments examined in this chapter bear markings that can be anachronistically characterised as *graphs*.[1] On all of them astronomical quantities are represented graphically by means of a procedure which achieves the transfer of the numerical entries of a previously calculated table on a two-dimensional surface. The table gives a discrete set of values of a mathematical function of one or more parameters, and the 'transfer procedure' defines the 'coordinate system' underlying the graphical representation of that function. Thus, each column or row of the table provides a series of points of a particular curve. The resulting markings, together with the scales allowing the user to enter the values of the arguments of the functions displayed, are often called 'nomograms'.[2] Medieval mathematical instruments deserve to be seen in the light of the history of nomography.[3] It is hoped that the framework which guided the organization of the present chapter will provide the modern reader with a new and useful way of looking at them.

[1] I use this word basically in its modern sense, as a graphical representation of the variation of a dependent quantity (the function) in terms of independent ones (its parameters), although in the case of ancient mathematical instruments this representation is by no means restricted to a Cartesian coordinate system, as sometimes specified in modern definitions of the term.

[2] The applied mathematical science of nomography was created in the second half of the nineteenth century. See d'Ocagne 1899, one of the classical textbooks on the topic. An inspiring essay on the history of the modern history of graphs and nomograms is Hankins 1999. See also Hankins & Silverman 1995.

[3] An insightful paper on the subject of graphical representations in medieval astronomy is North 1987.

Theory of nomograms of two parameters. Suppose function $z(x,y)$ represents the quantity to be found with a given mathematical instrument when arguments x and y are known. To represent a two-argument function in two dimensions, we need some kind of 'contour plot', that is, a family of curves representing our function for a regular range of discrete values, as on a topographic map; in this manner we can obtain the value of z (in most cases through visual interpolation) by somehow feeding in arguments x and y. (In the simple case of a topographic map we feed in the terrestrial latitude and longitude as Cartesian coordinates and read off the altitude corresponding to this location.) An horary quadrant works according to the same principle: it displays the time (for example the time since sunrise in seasonal hours τ) in terms of the solar altitude h and the solar declination δ, for integer values thereof (for example $\tau = 1, 2, \ldots, 6$). A geometrical procedure (equivalent to a 'coordinate system') for feeding in both arguments needs to be defined. The resulting curves are called the hour-lines.

In order to plot the function $x_3 = F(x_1, x_2)$ a table of an inverse function $x_1(x_3, x_2)$ is required for regular ranges of arguments x_3 and x_2. Through the geometrical procedure (or coordinate system) underlying a given instrument, it is then possible to transfer on it each entry of the table and to join the series of points with fixed argument x_3 (corresponding to one 'column' in the table) as individual curves.

Of course, graphs of quantities depending upon one parameter are also common on medieval mathematical instruments (for example, the solar altitude at a given time of prayer as a function of solar longitude or declination), and their representation follows the same procedure as outlined above.

Definitions. At the outset it is necessary to provide some definitions. In the following the term 'dial' will designate any portable instrument for time-keeping by the sun, the use of which presupposes a knowledge of the solar longitude, which can be entered on a scale. All instruments featured in this chapter are thus 'dials'. The term 'sundial' will be applied to any instrument involving the casting of shadows. Sundials belonging to the category 'dial' are usually described as 'portable sundials'. Fixed sundials, however, are not 'dials', since they indicate time without requiring any parameter to be entered by the user. They will be dealt with in Chapter 4.

I classify dials into three categories, depending on the nature of the quantities represented on them. The first category involves astronomical quantities expressed in terms of altitudes; the paradigmatic type of such instruments is the horary quadrant. The second category is that of instruments displaying shadow lengths, and the third one is that of azimuthal dials, instruments based only on the azimuthal direction of a shadow. This chapter will follow to the following scheme:

1. Dials displaying altitudes.

   (a) Horary quadrants: the solar altitude is measured by the operator and then entered on the instrument. This is the main category of instrument to be considered in this chapter; they are divided into two sub-categories, depending on whether

      i. the altitude is entered as a natural angular coordinate, or
      ii. the altitude is entered in a non-standard way.

   (b) Altitude sundials: the solar altitude is automatically 'entered' on the instrument by means of a gnomonic device (stick, hole). There exist two kinds:

      i. two-dimensional: vertical surface oriented in the azimuthal plane of the sun; a gnomon perpendicular to the surface casts a shadow which provides the solar altitude.
      ii. three-dimensional: ring dial.

2. Dials displaying shadow lengths: these include most types of portable sundials. There exist two kinds:

   (a) two-dimensional: "locust's leg", *ḥāfir*, and so forth;

   (b) three-dimensional: cylindrical and conical dials with movable gnomons.

3. Azimuthal dials: these are horizontal instruments provided with a gnomon, whose markings depend only upon the direction of the shadow.

The first category allows full liberty in the choice of the coordinate system. In the second and third cases, the use of shadows imposes physical limitations on the design of the instruments, which as a rule involve either rectangular or polar coordinates.

In descriptions of dials I shall use the following conventions. Rectangular coordinates are expressed by x and y, for the horizontal and vertical coordinates; unless otherwise specified, both coordinates are considered as *positive* distances from the origin of the coordinate system (usually the centre of the quadrant). Polar coordinates are noted with the symbols ρ for the radial distance and θ for the angular coordinate. In this chapter, the expression 'solar longitude' will always mean the distance to the nearest equinox, measured along the ecliptic, of a point of longitude λ; this quantity, λ', is defined in the interval $-90° \leq \lambda' \leq 90°$. The following table gives the equivalence $\lambda \leftrightarrow \lambda'$:

λ':	-90	-60	-30	0	30	60	90
λ :	270	300/240	330/210	0/180	30/150	60/120	90

Furthermore, the symbol R will represent the radius of a quadrant.

The standard markings on these dials are for the seasonal hours of day, but the possibilities are much more varied. Medieval astronomers have considered different functions that could be represented on horary quadrants. al-Bīrūnī mentions, besides the altitude at the seasonal hours $h_i^s(\lambda')$, the altitudes at the equal hours $h_i^e(\lambda')$ and at the beginning and end of the ʿaṣr prayer (h_a and h_b).[4] al-Marrākushī adds to these the altitude of the sun h_q when it stands in the azimuth of the *qibla*, or the solar altitude in the prime vertical h_0.[5] Although Najm al-Dīn only considers the quantities h_i^s and h_a, he describes in Ch. 4 a very refined quadrant on which the functions h_T and h_a are represented, allowing to determine the time since sunrise in equatorial degrees T and the azimuth a.[6]

3.1 *Altitude dials: horary quadrants and cognate instruments*

Horary quadrants are graphical devices for finding the time of day in terms of the solar longitude and the instantaneous altitude.[7] The focus here concerns horary quadrants for a specific latitude. Since it can be best described as a trigonometric instrument, the universal horary quadrant will be discussed in Chapter 5 together with the Sine quadrant. The horary quadrant for a specific latitude, like its universal counterpart, is an invention of early ninth-century Baghdad. The instrument is first attested in a short anonymous early ninth-century Abbasid tract that can possibly stem from al-Khwārizmī or his milieu.[8] In his treatise on astrolabes al-Bīrūnī discusses the horary quadrant as an instrument already well-known in his times, either as a component of the back of astrolabes or as a separate quadrant provided with sights and a silk thread with plumb bob and movable bead.[9] Actual examples are, however, extremely rare: the earliest one is featured on the back of the astrolabe made by Ḥāmid ibn ʿAlī in 343 H [= 954/5],[10] and also on the back of the splendid astrolabe made in 374 H [= 984/5] by the astronomer al-Khujandī.[11]

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[4] al-Bīrūnī, *Shadows*, pp. 236–238, and idem, *Istīʿāb*, MS Leiden UB Or. 591, pp. 88–89.

[5] al-Marrākushī, *Jāmiʿ*, I, pp. 365:22–366:3,20-25 and table on p. 367. Cf. Viladrich 2000, p. 288.

[6] The possibility of representing the time-arc since sunrise on an horary quadrant is also mentioned in an anonymous treatise preserved in MS Cairo ṬM 155/3, on f. 21v. Cf. n. 14 below.

[7] On horary quadrants in general, see Drecker 1925, pp. 86–89; Michel 1976, pp. 81–85 (both based on limited European sources); and for the Islamic tradition Viladrich 2000.

[8] The text is preserved in MS Istanbul Aya Sofya 4830, ff. 196v–197r. This is discussed in King 1983b, pp. 30–31; the text is edited and translated in Charette & Schmidl, "Khwārizmī".

[9] al-Bīrūnī, *Istīʿāb*, MS Leiden UB Or. 591, p. 89.

[10] See n. 32 on p. 60.

[11] See the description in King 1995, pp. 83–89 and the analysis of the quadrant in Stautz 1997, pp. 50–52.

Otherwise only two individual horary quadrants are known from before the Ottoman period, both dating from the thirteenth century.[12]

This instrument has been later developed in a wide variety of forms. al-Marrākushī presents four different types of horary quadrants for specific latitudes, three of them being not previously encountered in the literature.[13] An anonymous tract of uncertain date, presumably of Western Islamic origin, could represent, albeit in a corrupt form, the source al-Marrākushī relied upon, since several sentences are almost identical in both texts.[14] al-Marrākushī might have freely adapted the original version of this treatise for his *summa*, but we cannot exclude the possibility that both texts were independently derived from a third source. Together with these, Najm al-Dīn's treatise represents the only available manuscript source in which this category of instruments is featured. It is also the richest of them since it describes the construction of eight different types,[15] six of them being completely new.

The horary quadrants of al-Marrākushī were briefly presented by L. A. Sédillot[16] and described in more details by Schmalzl in his essay on Islamic quadrants.[17] Recently Mercè Viladrich surveyed all available material and textual sources concerning horary quadrants designed for specific latitudes, including Najm al-Dīn's treatise. Her study, although useful in general, introduces at several places more confusion than it throws light on the subject; it is also marred with some serious errors of interpretation and a superficial classification scheme.[18]

To construct the hour-lines on an horary quadrant one needs a table of the function $h_i^s(\lambda')$; such a table is provided by Najm al-Dīn in Ch. 80 (see Table T.14 on p. 310): its entries are for $i = 1, 2, \ldots, 6$ and $\lambda' = -90°$, -60, $\ldots$, $90°$, and it also includes values of the quantities h_a and h_b.

Generally, the orientation of quadrants described in medieval Arabic sources corresponds to the upper-left quadrant of a circle. The intersection of the perpendicular radii delimiting it is called the centre (*markaz*) of the quadrant. The horizontal side is the "east line" (*khaṭṭ al-mashriq*), and the vertical one is designated as usual the 'meridian line' (*khaṭṭ niṣf al-nahār*). The rim of the quadrant bears an altitude scale (*qaws al-irtifāʿ*) graduated with 90 divi-

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[12] They are listed in Viladrich 2000, p. 283; one of them is described in King 1995, pp. 91–93, the second one is illustrated in the article "Rubʿ" in *EI*[2], VIII, pp. 574–575, pl. XXXII (by D. A. King).

[13] These are contained in *fann* 2, *qism* 4, *faṣl* 2, on the construction of the quadrant: see al-Marrākushī, *Jāmiʿ*, I, pp. 365–371; cf. Sédillot, *Mémoire*, pp. 73–81.

[14] It is preserved in the unique manuscript Cairo ṬM 155/3, ff. 19r–21v. Apart from a photocopy of the manuscript I have also had access to a typewritten edition of this text by David A. King. See also Viladrich 2000, pp. 285, 309, 311.

[15] Not counting the quadrant presented in Ch. 71, equivalent to the one in Ch. 66.

[16] Sédillot, *Mémoire*, pp. 73–81.

[17] Schmalzl 1929, pp. 118–124.

[18] Viladrich 2000.

sions numbered from the east line to the meridian. Each quadrant should be provided with sights along the vertical side in order to measure altitudes: this is never mentioned in the text, since the reader is assumed to be well aware of such practical details. In most cases a thread (*khayṭ*) with movable bead (*murī*) is attached at the centre. But on some quadrants the thread is attached at the beginning or end of the altitude scale, while others even need to be fitted with two threads.

3.1.1 *Horary quadrants with the altitude as the angular coordinate*

It is only natural that the 90°-scale delimiting a quadrant, which is systematically called the "altitude arc" (*qaws al-irtifāʿ*), should serve to feed in the altitude. Hence the majority of horary quadrants described by al-Marrākushī and Najm al-Dīn, and also those of the European tradition, have the property of displaying the altitude as a natural angular coordinate. On such quadrants, the time can be determined simultaneously with measuring the altitude, just by looking at the intersection of the appropriate day-circle (or day-line) with the thread. Within this category of horary quadrants, what distinguishes one type from another will be the sole geometrical layout of the markings corresponding to the solar longitude, whose design is arbitrary.

Horary quadrants with radial longitude scales

Textual sources prior to *ca*. 1200 mention the same type of horary quadrant for a specific latitude, which I label the 'classical' type.[19] The two extant examples from the same period also feature this type.[20] The classical horary quadrant is characterised by sigmoid curves defined mathematically through a system of polar coordinates ρ, θ, where the angle θ is the instantaneous altitude h and the radius ρ is a linear function of the solar longitude λ', which is fed in on a uniform scale along the radius. A common variant of this makes use of a declination scale (with $\rho \propto \delta$) instead of a longitude one. Both types of scales can run from summer to winter solstice, or vice versa, with inevitable consequences for the appearance of the hour-lines.[21]

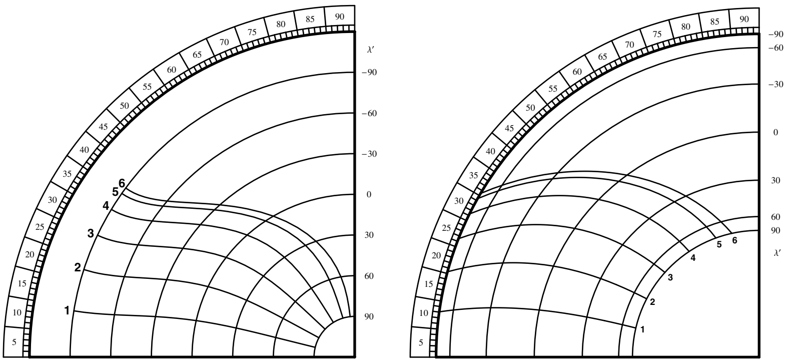
A uniform longitude scale is constructed along one of the sides by dividing it (or a portion of it) into equally-spaced divisions for regular intervals of the solar longitude. al-Marrākushī suggests dividing each side of the quadrant into eight equal parts: these define the radii ρ_i of seven equidistant day-circles, with $\rho_i = iR/8$ $(1 \leq i \leq 7)$.[22] This quadrant is illustrated on Fig. 3.1a. In terms

[19] See p. 116, nn. 8 and 9.

[20] See p. 116 above for references to the texts and instruments.

[21] Various variants of the 'classical' horary quadrant (usually displaying equal hours) were popular in Europe during the period 1300–1700.

[22] al-Marrākushī, *Jāmiʿ*, I, pp. 366:4-22; cf. Sédillot, *Mémoire*, pp. 73–75; Schmalzl 1929, p. 121.



(a) with uniform longitude scale

(b) with uniform declination scale

FIG. 3.1. Two horary quadrants of the classical type

of the solar longitude, these can be expressed as follows:

$$\rho(\lambda') = \tfrac{R}{2} - \tfrac{3}{8}\lambda' \qquad (\text{with} \quad -90^\circ \leq \lambda' \leq 90^\circ \quad \text{and} \quad R = 90).$$

An horary quadrant with radial scale linearly dependent on the declination can be defined by setting an arbitrary value r for the radius of the innermost day-circle. The radius of a day-circle of declination δ will then be defined as

$$\rho(\delta) = \frac{R+r}{2} \pm \frac{R-r}{2\varepsilon}\delta\,.$$

When the sign between both terms is positive, then the outermost day-circle will correspond to the summer solstice, and if it is negative it will correspond to the winter solstice. A clever way to define the declination scale would be to set $R = \max(h_m) = 90 - \phi + \varepsilon$ and $r = \min(h_m) = 90 - \phi - \varepsilon$, so that $\rho(\delta) = 90 - \phi \pm \delta$; when the outer day-circle represents summer solstice, the radii are simply given by the meridian altitude h_m (see Fig. 3.1b). We shall encounter in Section 3.1.2 examples of horary quadrants on which one radial coordinate is indeed defined by the meridian altitude h_m. Both al-Marrākushī and Najm al-Dīn omit any discussion of this type, but the latter proposed an alternative construction which approximates it extremely well (see below).

A third possibility would be to define the longitude scale according to stereographic projection. As far as I know, this is not attested on any Islamic quadrants before the late Safavid period.[23] Many late Safavid astrolabes from

[23] The best example of a European quadrant using stereographic day-circles is of course the instrument known as "Gunther's quadrant", on which see Bion 1758, pp. 193–197 and Drecker 1925, pp. 88–89.

Isfahan have in the upper-right quadrant of the back two sets of graphs. The first one displays curves of the meridian altitude $h_m(\delta)$ for a range of latitudes, and the second one displays curves of the solar altitude in the azimuth of Mecca $h_q(\delta)$ for various localities. The radii of the day-circles correspond to a stereographic projection (i.e., $\rho(\delta) = R_E \tan(45° - \delta/2)$). For the graphs of h_m a southern projection is used (Capricorn is the innermost day-circle), and for the graphs of h_q a northern projection (Cancer is the innermost day-circle). In this manner one avoids the confusion which would result from a superposition of similarly-oriented curves.[24]

Quadrants with irregular declination scales defined regressively

Instead of proposing the construction of an horary quadrant with a uniform declination scale following the above scheme, Najm al-Dīn chose a different path, which nevertheless led to the same result. The horary quadrant featured in Ch. 67 has indeed an appearance practically identical to the classical horary quadrant with uniform decreasing declination scale illustrated in Fig. 3.1b.

Here, the midday hour-line is *defined* as an exactly circular arc. This leads to a *regressive* construction of a longitude scale which is directly dependent on the circular shape of the midday hour-line. The remaining hour-lines can then be constructed in terms of this irregular longitude scale, but since their shape will also be very close to circular arcs, they can conveniently be approximated as such. This horary quadrant is an example of an important aspect of nomographic developments, where the irregularity of a particular curve is transferred to the associated scale. Further cases of regressively defined scales shall follow in this chapter.

Najm al-Dīn gives the inner radius of the quadrant featured in Ch. 67 (which is of course arbitrary) as $r = \varepsilon$ and omits to specify the outer radius R; the illustration, however, suggests that $R = 60$.[25] Since the equinoctial day-arc is exactly in between, its radius will be given by $\frac{60+\varepsilon}{2}$. Once the three day-arcs of the solstices and equinox are traced, the ruler is put at the centre and upon the meridian altitude at the solstices and equinox and marks are made on them, defining three points of the sixth hour-line, which is drawn as a circular arc passing through them. Then the longitude scale is defined regressively from the sixth hour-line, as follows (see Fig. 3.2):

Put the ruler at O and upon the meridian altitudes I, J, K at winter solstice, equinox and summer solstice, and mark points I, L and M at the intersection of the ruler with their respective day-circles. Find the centre N of a circle passing through I, L and M, and trace a circular arc from I to M. For each value of the solar longitude λ' to be marked on the radial scale, put the ruler at

[24] On these quadrants, see Michel 1976, pp. 78–81 and King 1999, pp. 186–193.

[25] Here we have the fortuitous coincidence that the ratio $r/R = \varepsilon/60$ corresponds almost perfectly to the ratio $\min(h_m)/\max(h_m) = (90 - \phi - \varepsilon)/(90 - \phi + \varepsilon)$ when $\phi = 36°$ (actually the equivalence is exact for $\phi = 35.87°$). This probably explains the particular choice of r as ε.

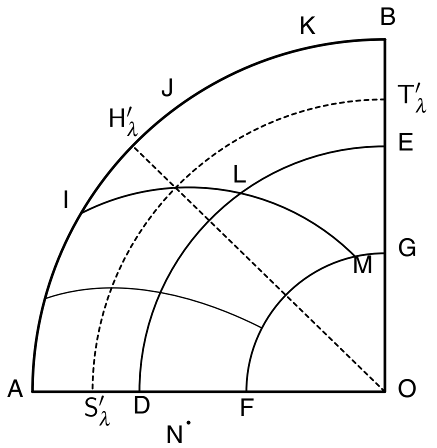


FIG. 3.2. Construction procedure in Ch. 67

O and upon its corresponding meridian altitude H'_λ, and mark its intersection with arc ILM. Open the compass to this mark and trace arc $T'_\lambda S'_\lambda$ which will represent the appropriate day-circle. Once all day-circles are traced, the hour-lines 1 to 5 can be constructed without any difficulty: mark for each zodiacal sign the altitude of each hour on the corresponding day-circle and join the resulting marks to form regular curves: Najm al-Dīn suggests joining them as circular arcs if possible, or pointwise.

The radius of a day-circle of declination δ is expressed by a non-trivial expression:

$$\rho(\delta) = \cos h_m \Big(-x_0 + y_0 \tan h_m + \sqrt{(r_0{}^2 - x_0{}^2 - y_0{}^2)\sec^2 h_m + (x_0 - y_0 \tan h_m)^2} \Big),$$

with $h_m = 90 - \phi + \delta$, (x_0, y_0) are the coordinates of the centre of the circular arc representing the midday hour-line and r_0 is its radius.[26] Numerical comparison of the radii resulting from this regressive construction procedure with those of an authentic declination scale yields the following (we assume $R = 60$, $r = \varepsilon$ and $\phi = 36°$):

[26] I have refrained from reproducing here the monstrous analytical expression for x_0 and y_0, which can be found numerically. The radius, however, can be more easily expressed in terms of these as

$$r_0 = \sqrt{(x_0 + R\sin\phi)^2 + (y_0 - R\cos\phi)^2}\,.$$

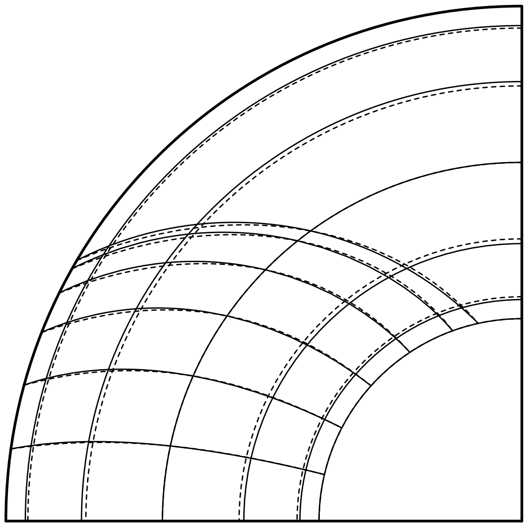


FIG. 3.3. Uniform declination scale vs. regressive construction

λ'	$-90°$	$-60°$	$-30°$	$0°$	$30°$	$60°$	$90°$
$\rho(\lambda')$ (decl.):	60	57.444	50.701	41.792	32.882	26.140	23.583
$\rho(\lambda')$ (regr.):	60	57.734	51.207	41.792	32.327	25.804	23.583

The coincidence is thus excellent, and it simply reflects the fact that the hour-lines on an horary quadrant with 'real' declination scale are indeed very close to being circular arcs. A superposition of the markings of an horary quadrant with uniform declination scale (dashed) upon those of an horary quadrant whose scale is constructed regressively (continuous) is shown in Fig. 3.3.

A variant with increasing scale. A variant of the same instrument, this time with increasing longitude scale, is presented in Ch. 73. This quadrant is called 'horary (quadrant) with the equation circles' (*sāʿāt dawāʾir al-taʿdīl*).[27]

The construction procedure is exactly the same as with Ch. 67, except for the following differences: the scale is now decreasing: the outermost day-circle corresponds to summer solstice and the innermost one to winter solstice. The radius of the innermost circle is defined by the following geometrical construction: one leg of the compass is placed at the beginning of the altitude arc, and the other one on its 45° division; this distance is then transfered to the horizontal side, without moving the first leg; the resulting length of the

[27] Viladrich 2000, p. 298, translates this wrongly as "proportional circles".

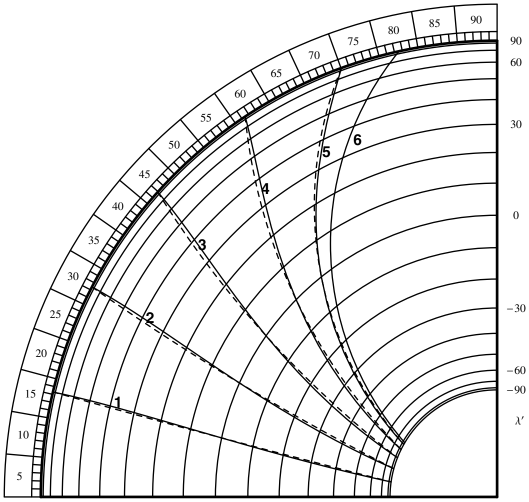


FIG. 3.4. The horary quadrant with "circles of equation"

smallest radius can thus be expressed as

$$r = R - \text{Chd}\,45^\circ = R - R\sqrt{2-\sqrt{2}}.$$

Also, day-circles are traced for each 10° of the solar longitude. The rest of the construction is exactly as in Ch. 67, and the result is illustrated in Fig. 3.4. Najm al-Dīn suggests joining the marks defining the hour-lines "with the compass as circular arcs": this presumably assumes that only three marks are made for the solstices and equinox. Although not absolutely accurate, this approximation of the exact curves would be almost undiscernible on an actual instrument of modest size (see Fig. 3.4, where the exact curves are continuous and the circular arcs are dashed).

The name "circles of equation" probably refers to the day-circles: the slight displacements of the radii that result from imposing a circular shape on the sixth hour-line present indeed an analogy to the equation or correction (*taʿdīl*) applied to planetary mean motions. The following table gives the radii of a uniform increasing declination scale compared to the above construction (assuming $R = 60$ and $r = R(1 - \text{chd}\,45^\circ) = 14.078$):

λ'	-90°	-60°	-30°	0°	30°	60°	90°
$\rho(\lambda')$ (decl.):	14.078	16.664	24.845	37.039	48.993	57.173	60
$\rho(\lambda')$ (regr.):	14.078	17.302	25.804	37.039	48.274	56.776	60

We see that the differences are again very slight.

Similar types of horary quadrants with circular hour-lines (for the equal hours) are occasionally found on medieval European quadrants or astrolabes. They are also designed by tracing first a circular arc for the midday hour-line, which serves to define the solar longitude scale, exactly as Najm al-Dīn did but according to a different geometrical design. The earliest examples are three English brass quadrants made by the same person (two of them dated 1398 and 1399).[28] Their construction is far simpler: the midday curve is a semicircle centred on the vertical side of the quadrant, with a radius of one half the radius of the quadrant, exactly as the midday hour-line on a standard universal horary quadrant. The radial declination scale that derives from such a construction is irregular and bears no direct relationship to Najm al-Dīn's model.[29] There are some more examples horary quadrants (from the Renaissance and even later) designed according to this principle, but with arbitrary layouts for the midday circular arc.

Two horary quadrants of al-Marrākushī with straight day-lines

The horary quadrant described in Ch. 70 is the only one which Najm al-Dīn reproduced from al-Marrākushī without modification.[30] It is characterised by straight vertical day-lines going from the altitude scale to the horizontal side. The extremity of each day-line on the altitude scale coincides with the meridian altitude corresponding to its declination ($h_m = 90 - \phi + \delta$). The parametric expression for the hour-lines can be expressed as

$$x = R\cos h_m$$
$$y = R\cos h_m\ \tan h\,.$$

The resulting markings are illustrated in Fig. 3.5a and on Plate 7. al-Marrākushī also proposed an alternative construction: instead of being vertical, the day-lines now converge to the point on the horizontal side that is at the base of the equinoctial day-line.[31] This leads to crowding the hour-lines a little more,

[28] These quadrants are described in details in Ackermann & Cherry 1999; the authors, however, do not discuss the horary markings *per se*.

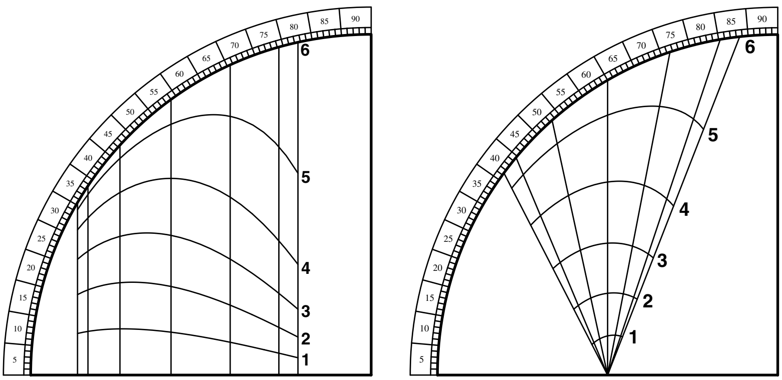
[29] The construction of such horary markings is discussed in Michel 1976, pp. 82–84. On these English quadrants the radius of a day-circle is given by $\rho(\delta) = R\sin(90^\circ - \phi + \delta)$. Their maker only marked the day-circles of the solstices and equinox; he also traced all hour-lines as circular arcs (which corresponds to Najm al-Dīn's suggestion in Ch. 73). On one of the three quadrants a zodiacal scale and day-circles for each 10° of longitude were added in the late sixteenth century (Ackermann and Cherry, p. 10).

[30] al-Marrākushī, *Jāmiʿ*, I, pp. 367:13–368:8; cf. Sédillot, *Mémoire*, pp. 77–78; Schmalzl 1929, pp. 121–122.

[31] al-Marrākushī, *Jāmiʿ*, I, pp. 369:16–370:19; cf. Sédillot, *Mémoire*, pp. 73–75; Schmalzl 1929, pp. 123–124.

and is of little practical or æsthetical advantage (see Fig. 3.5b).[32]

For both quadrants al-Marrākushī warns that "the design is unfeasible for localities whose latitudes are equal to the obliquity, or smaller".[33] In fact the design of these two quadrants is perfectly feasible for subtropical latitudes, but it will present irregularities which might have disturbed a medieval instrument-maker. In such cases most horary quadrants will only display an irregular pattern for the midday line, and the markings will remain functional. Other quadrants, however, are by nature impossible to design when $\phi < \varepsilon$ or when $\phi > 90^\circ - \phi$ (see further p. 128).



(a) (b)

FIG. 3.5. al-Marrākushī's two horary quadrants with straigth day-lines

[32] This geometrical *caprice* also makes our parametric equations sensibly more complicated:

$$x = \frac{R \sin h_m \ \sin \phi}{\sin h_m + \tan h \ (\sin \phi - \cos h_m)} \quad \text{and} \quad y = \frac{R \sin h_m \ \sin \phi \ \tan h}{\sin h_m + \tan h \ (\sin \phi - \cos h_m)}.$$

[33] *iʿlam anna hādhā al-rasm yataʿadhdharu fī 'l-bilād allatī ʿurūḍuhā mithl al-mayl al-aʿẓam wa-aqall*. al-Marrākushī, *Jāmiʿ*, I, pp. 368:7–8, 370:12-13. The same observation is also made on p. 369:14-15 concerning his third horary quadrant (see pp. 127–128).

The horary quadrant with the angle

The quadrant featured in Ch. 75 also bears straight day-lines, defined as equidistant diagonals running parallel to the chord subtended from the beginning to the end of the quadrant. The day-line of Cancer corresponds to the chord of the quadrant, and the day-line of Capricorn meets the sides of the quadrant at one third of its radius, measured from the centre. Each day-line thus forms the diagonal of a square with sides of length $s(\lambda') = \frac{R}{3}(2+\lambda'/90)$.

Najm al-Dīn's representation of this instrument is limited to an isosceles right triangle, the altitude scale of the quadrant being projected onto a diagonal scale running along the outermost day-line (see Plate 8). Despite the triangular design Najm al-Dīn bestowed upon this instrument, it nevertheless does qualify as a 'quadrant', and it is represented as such in Fig. 3.6. This instrument is not known from other sources.

The hour-lines can be expressed in terms of these parametric equations:

$$x(\lambda',n) = (\tfrac{2}{9}\,\lambda' + 40)\,\frac{1}{1+\tan h(\lambda',n)}\,,$$
$$y(\lambda',n) = (\tfrac{2}{9}\,\lambda' + 40)\,\frac{\tan h(\lambda',n)}{1+\tan h(\lambda',n)}\,.$$

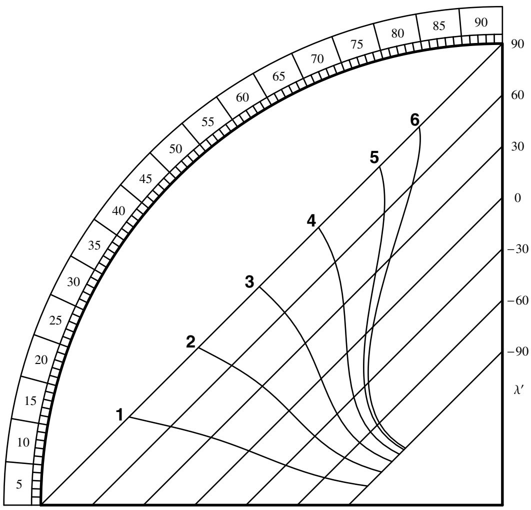


FIG. 3.6. Najm al-Dīn's horary quadrant with the angle

Two horary quadrant with ‘bi-angular’ coordinates

Horary quadrants of this category are characterised by having a bundle of straight day-lines radiating from the beginning of the altitude scale. The anonymous treatise on horary quadrants already mentioned (p. 117) counts them within the larger category of “sailed” quadrants (*qilʿī* or *bi-shakl al-qulūʿ*), because their markings are like the sails of a ship. This analogy is judicious for any quadrant with straight day-lines converging at one point: these include al-Marrākushī’s fourth horary quadrant described above (see Fig. 3.5b) – which can also be described in terms of ‘bi-angular’ coordinates – as well as the two quadrants under discussion (see Figs 3.8 and 3.10).[34]

On such quadrants it is possible to express the coordinates of a point of the hour-lines as resulting from the intersection of two straight lines radiating from A and O, and making angles θ and h with respect to line AO, where θ is some cumbersome function of λ' (see Fig. 3.9). The Cartesian coordinates of point P can be written as

$$x = \frac{R}{1+\tan h\cot\theta} \qquad \text{and} \qquad y = \frac{R\tan h}{1+\tan h\cot\theta}\,.$$

(Note that on a quadrant OAB we shall always define the positive x-axis by means of radius OA, thus pointing towards the left on our examples.)

al-Marrākushī’s instructions for the construction of the third type can be summarised as follows (see Fig. 3.7).[35] On quadrant OAB trace a smaller quarter of a circle HT with arbitrary radius. Put the ruler on O and on the meridian altitude at summer solstice D ($\widehat{AD} = 90^\circ - \phi + \varepsilon$) and mark K on HT. Put the ruler on O and the meridian altitude at winter solstice C ($\widehat{AC} = 90^\circ - \phi - \varepsilon$) and mark M at an arbitrary location, provided it is near the centre O. Trace segment MK which will be the midday hour-line. To trace a day-line for longitude λ', put the ruler on the corresponding meridian altitude E and mark L on MK: line HL will be the desired day-line. The construction of the hour-lines is as usual. The anonymous treatise presents essentially the same instructions (without the superfluous ‘small quadrant’ HT); the instruction for determining point M is, however, missing in this text. A universal variant of this quadrant is also described, with the midday hour-line going from the end of the quadrant B to some point on line OA, not too far from the centre.

In my reconstruction of the instrument I have – as in the anonymous treatise – neglected al-Marrākushī’s ‘small quadrant’, so that K coincides with D.

[34] The anonymous treatise describes the two quadrants of this type that are featured in al-Marrākushī’s treatise (third and fourth quadrants). But since the standard universal horary quadrant (see Section 5.2) is also described as a “sailed” quadrant, it is difficult to understand the criteria involved.

[35] al-Marrākushī, *Jāmiʿ*, I, pp. 368:9–369:16; cf. Sédillot, *Mémoire*, pp. 78–80; Schmalzl 1929, pp. 122–123.

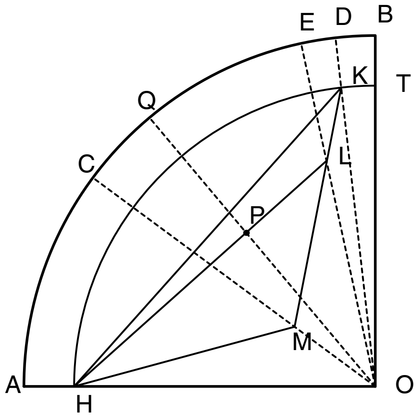


FIG. 3.7. Construction of al-Marrākushī's third horary quadrant

Moreover, I have chosen the location of M in such a way that KM forms a vertical, as in the illustration of MS Istanbul Topkapı Ahmet III 3343.[36] Given this simplification it can be shown that angle θ is given by:

$$\tan\theta(h_m) = \frac{\cos(90^\circ - \phi + \varepsilon)\ \tan h_m}{1 - \cos(90^\circ - \phi + \varepsilon)}\,.$$

This procedure requires that the midday hour-line be straight.[37] A major inconvenient feature of this quadrant is that the day-lines for southern declinations are cluttered. al-Marrākushī rightly says that it is not possible to construct this quadrant when $\phi \leq \varepsilon$.[38] Actually, the construction is only possible in the range $\varepsilon < \phi < 90^\circ - \varepsilon$, as the reader will easily convince itself. Let us now examine Najm al-Dīn's version.

[36] al-Marrākushī, *Jāmiʿ*, I, p. 369.

[37] Someone in Renaissance Europe also invented an horary quadrant with straight hour-lines called *quadrans bilimbatus*. The radial longitude scale is so designed that the divisions for northern and southern declinations coincide (hence the double scale which gives the name to the quadrant): the hour-lines are made of two segments that meet at the equinoctial line. The idea of using a 'folded' scale was later applied on Gunther's quadrant (see n. 23 above). The first recorded occurrence of this quadrant is in a manuscript by Jakob Ziegler dated 1500 (see Drecker 1925, p. 87). Johann Stoeffler described the construction and use of this quadrant in his book on the astrolabe published in 1524 (see Stoeffler, *Elucidatio*, ff. 65r–66v). This instrument was also illustrated shortly thereafter (before 1527) by Georg Hartmann in an elegant autograph pergament manuscript (MS Weimar Landesbibliothek fol. max. 29, f. 65v); on this manuscript see Zinner 1956, p. 359.

[38] See the reference in n. 33, on p. 125.

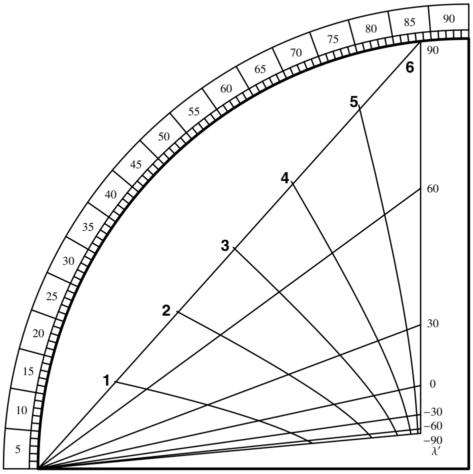


FIG. 3.8. al-Marrākushī's third horary quadrant

Najm al-Dīn's variant. Najm al-Dīn presents in Ch. 69 a variant of al-Marrākushī's third horary quadrant, on which the midday hour-line becomes a circular arc instead of a straight line. This apparently innocuous modification turns out to be a serious complication: the quadrant becomes "crowded ..., difficult to draw and of doubtful use".[39] Nevertheless, from the perspective of 'nomographic recreations', this quadrant, as many others, is of great interest.

The construction procedure described in the text can be reproduced as follows (see Fig. 3.9). On quadrant OAB trace the diagonal AB and determine on OB an arbitrary point C, with the restriction that it be nearer to the centre than the horizontal projection of E, the meridian altitude of Capricorn, on OB. Next, find the midpoint D of segment CB. Let E, F and G be the meridian altitudes at Capricorn, Aries and Cancer. Find the respective intersections K, L and M of OE with AC, OF with AD and AB with OG. The circular arc KLM passing through these three points will be the midday hour-line. The remaining day-lines are found in the same manner as on the previous quadrant.

On the illustration of **D** and **P**, point C appears to be chosen to coincide with one third of the radius (i.e., $OC = R/3$). I have hence adopted this convention for my reconstruction below. The analytic expression for the angle θ

[39] Viladrich 2000, p. 310.

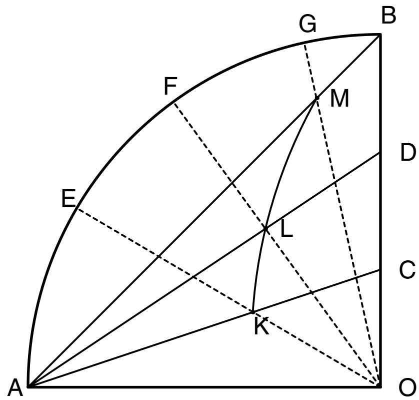


FIG. 3.9. Construction of the quadrant in Ch. 69

made by a day-line at A is given by:

$$\theta(h_m) = \arctan\left(\frac{\alpha\left(-x_0 + y_0\,\alpha\sqrt{r_0^2(1+\alpha^2)-(y_0+x_0\,\alpha)^2}\right)}{R + x_0 - y_0\,\alpha + R\,\alpha^2 - \sqrt{r_0^2(1+\alpha^2)-(y_0+x_0\,\alpha)^2}}\right),$$

where $\alpha = \tan(h_m)$, and (x_0, y_0) are the coordinates of the centre and r_0 is the radius of the circular arc defining the midday hour-line.

Because of the resemblance of the markings on this quadrant with a Persian harp (see Fig. 3.10), it is called "horary (quadrant) with the harp" (*sāʿāt al-junk*).[40] The plotting of the hour-lines is not possible for latitudes less than the obliquity ($\phi < \varepsilon$), because in such cases it is not possible to represent the sixth hour-line as a circular arc, which is a basic condition for constructing this quadrant.

3.1.2 *Horary quadrants on which the altitude is entered in a non-standard way*

With the following categories of quadrants, the instantaneous altitude, instead of being a natural angular coordinate, is entered as a *length* found by adjusting the bead on the thread with respect to a scale.

Inverse polar coordinates

The classical horary quadrant uses polar coordinates with the radius expressed in terms of the solar longitude and the angular coordinate being the altitude;

[40] The Arabic word *junk* comes from Persian *chang*. In Steingass's *Persian-English Dictionary* I notice the charming entry "chang rubʿwash (rubʿī), a musical instrument in the shape of a quadrant or astrolabe".

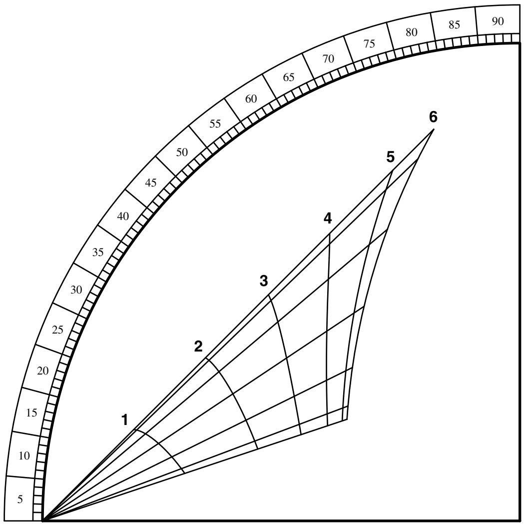


FIG. 3.10. Najm al-Dīn's "horary quadrant with the harp"

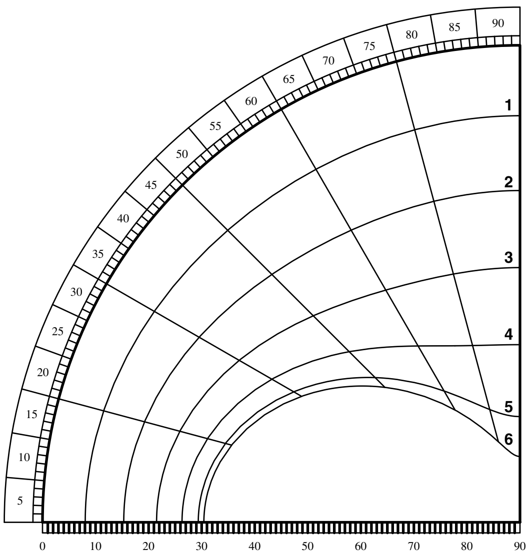


FIG. 3.11. Horary quadrant with inverse polar coordinates

a quadrant on which the situation is reversed can be imagined, namely, with the radius expressed in terms of the altitude and the angle expressed in terms of the longitude: this is exactly the situation defining the horary quadrant presented in Ch. 72. The hour-lines are represented with coordinates:

$$\rho = 90 - h \qquad \text{and} \qquad \theta(\lambda') = 90 - \lambda'/2 .$$ [41]

The day-lines are thus drawn as *radial* lines joining centre O to each multiple of 15° on the altitude scale AB. The longitude scale, instead of being marked on or along arc AB, is traced as a narrow circular band alongside the sixth hour-line. It is probably the shape of this scale which inspired the designation "quadrant with the *shaẓiyya*".[42] The altitude can be entered with the thread by setting the bead to the appropriate altitude on the nonagesimal scale AO, numbered from A to O. The result is illustrated in Fig. 3.11.

The horary quadrant with the chord

On this quadrant (Ch. 68) the vertical side OB is divided into six equal parts; the day-lines are straight lines going from the beginning of the altitude scale A to each subdivision of line OB (see Fig. 3.12). To construct the hour-lines, place the compass at A and at each value Q of the altitude of the hours from the table of $h_i^s(\lambda')$ on arc AB (so that arc $AQ = h$), and transfer this length AQ on the appropriate day-line AD, and mark it at P. The hour-lines are traced by joining their respective marks as individual curves (*qaws*^{an}). If this is not possible (presumably for practical reasons), Najm al-Dīn suggests joining them through linear segments *khuṭūṭ*^{an} *muqaṭṭiʿat*^{an},[43] or, if both methods fail, to join them by marking a succession of points in-between (*fa-jmaʿhā nuqaṭ*^{an}).

The name of the instrument (*sāʿāt al-watar*) no doubt stems from the observation that the length $AP = AQ$ measures the Chord of the altitude h:

$$AP = AQ = \mathrm{Chd}\,\angle AOQ = \mathrm{Chd}\,h = 2R\,\sin(h/2)\,.$$

Furthermore, the angle $\theta(\lambda') = \angle OAD$ made by day-line AD with AO will be given by:

$$\theta(\lambda') = \arctan\left(\frac{\lambda' + 90^\circ}{2R}\right).$$

[41] It would be theoretically possible to have $\rho = h$, but then the hour-lines would occupy less than one half of the surface of the quadrant, and the first hour-line would get very close to the centre. However, at low latitudes (below 30°), this choice of coordinates should be preferred over a radius of $90 - h$, especially when $\phi \leq \varepsilon$ (in which case the midday curve will present an irregular shape).

[42] On the reading and probable interpretation of this word, see my remark on p. 299, n. 1.

[43] Oddly enough we are told to do this with the compass, but the text might be corrupt or lacunary.

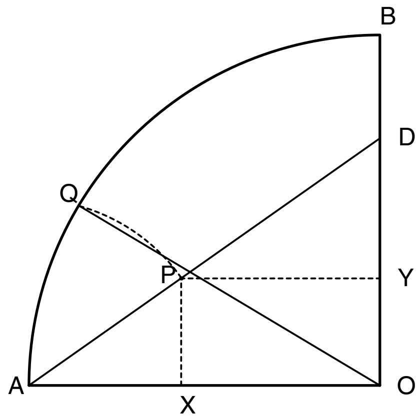


FIG. 3.12. Construction of the quadrant in Ch. 68

The coordinates $(x,y) = (OX,OY)$ giving the parametric equations for the hour-lines are:

$$x = R - 2R\sin(h/2)\,\cos\theta(\lambda')$$
$$y = 2R\sin(h/2)\,\sin\theta(\lambda')\,.$$

The resulting markings are shown in Fig. 3.13. For $\phi < 30°$ it is not possible to represent all curves completely within the area of the quadrant.

Quadrants with 'bi-radial' coordinates

On the following quadrants, both the altitude and the solar longitude are entered by means of radial coordinates measured by setting the beads of two threads.

Two horary quadrants with almost equidistant hour-lines. Najm al-Dīn's treatise features two horary quadrants, each named differently, but with identical coordinate systems. The first one (Ch. 66) is said to have been invented by the author in order that the hour-lines be as equally-spaced as possible; according to Najm al-Dīn, this feature makes this horary quadrant superior to other types, on which the fifth and sixth hour-lines are sometimes so close as to be hardly distinguishable. This new quadrant is hence described as the "quadrant whose sixth hour-line has the same width as its first one, each of them having a uniform width" (see Plate 6). As shall be seen, its hour-lines are indeed *almost* equidistant.

This quadrant features 'bi-radial' coordinates, which we explain with reference to Fig. 3.14. Two threads are attached at the centre of the quadrant O

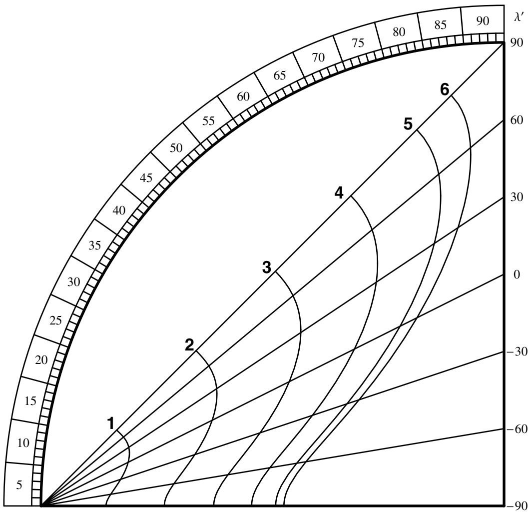


FIG. 3.13. The horary quadrant with the chord

and at the beginning of the altitude scale A. A scale is made along the horizontal side OA, with 90 equal divisions numbered from O to A. The solar longitude is entered by setting the bead of the thread attached at O to the corresponding meridian altitude h_m at K on scale OA, and the instantaneous altitude h is entered by setting the other thread to L on the same scale. The two threads are then rotated until both beads coincide at P: this position allows one to read off the hour of day.

The position of any point P on the hour-lines can be expressed by means of its distance from the centre of the quadrant O and its distance from point A. If the first distance OP is denoted by ρ_1 and the second one AP by ρ_2,

$$\rho_1 = h_m \quad \text{and} \quad \rho_2 = 90 - h,$$

assuming the radius of the quadrant R to be 90. The three day-circles EF, CD and GH for summer solstice, equinox and winter solstice, are traced according to the definition for ρ_1. Also, a circular arc UV centred at A with radius $\rho_2 = 90$ is traced between the day-circles of the solstices EF and GH: since this arc corresponds to $h = 0°$ it is called the "horizon". At midday $h = h_m$, so that $\rho_1 + \rho_2 = 90$: the midday hour-line will coincide with line LE on the horizontal radius. The altitude at each hour from one to five can be marked on the three day-circles, and these marks are joined through circular arcs approximating the exact curves with near perfection (graphically no difference is perceptible). It is possible to show – after a few algebraic manipulations

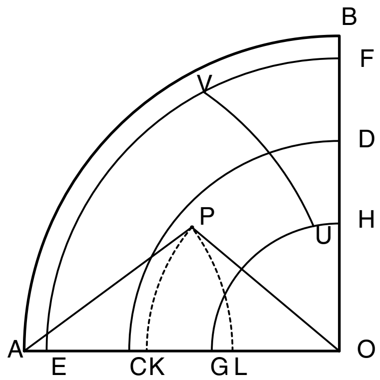


FIG. 3.14. The ‘bi-radial’ coordinate system in Ch. 66

– that the analytic expression for the hour-lines can be given in rectangular coordinates as follows:

$$x(h_m,h) = \tfrac{-1}{2R}\,(h_m^2 - h^2 + 2Rh)$$
$$y(h_m,h) = \tfrac{1}{2R}\,\sqrt{((2R-h)^2 - h_m^2)\,(h_m^2 - h^2)}\,.$$

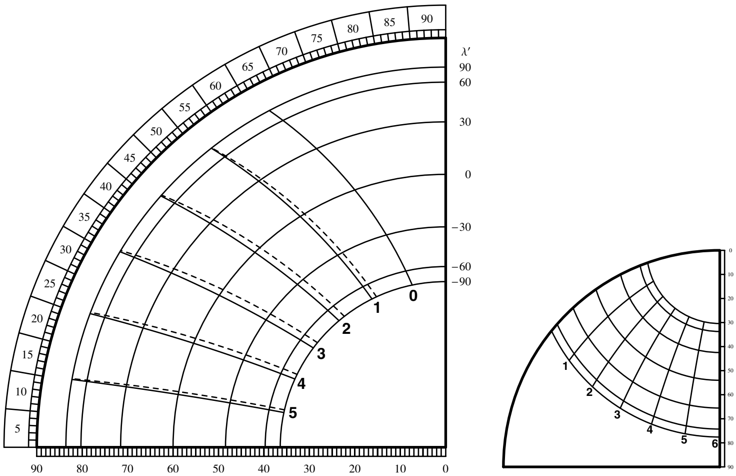
The sixth hour-line coincides with the horizontal radius of the quadrant. This quadrant is represented in Fig. 3.15a; in the treatise it is illustrated for a latitude of 30°.

Najm al-Dīn also mentions in passing an alternative method to draw the hour-lines: he suggests dividing the portion underneath the zero hour-line of each day-circle into 6 equal part, and to join these divisions through circular arcs. The resulting hour-lines are obviously inaccurate; a graphical comparison of the approximate and accurate curves is represented in Fig. 3.15, where the approximate arcs are dashed.[44] Furthermore, the illustration of this quadrant in both manuscripts is in error, and this error is related to a sentence in the text which appears to imply that by dividing the outer scale at each 10°, one would obtain six equidistant divisions for the hours, presumably on the

[44] Since the approximate construction is latitude independent, it is of interest to determine the underlying formula for the time as a function of the altitude and the meridian altitude, and to compare it with the standard universal formula. The time in seasonal hours τ underlying Najm al-Dīn’s alternative procedure can be expressed as

$$\tau = 6\left(1 - \frac{\theta}{\theta_{\max}}\right) \quad \text{where} \quad \theta = \arccos\left(\frac{h_m^2 + 180\,h - h^2}{180\,h_m}\right) \quad \text{and} \quad \theta_{\max} = \arccos\left(\frac{h_m}{180}\right).$$

Numerical comparison reveals that this hypothetical formula would be far less satisfactory than the approximation achieved with the standard universal formula. Also, it is acceptable only when $\delta \approx \varepsilon$.



(a) Version of Ch. 66

(b) Variant in Ch. 71

FIG. 3.15. Horary quadrants with (almost) equidistant hour-lines

day-circle of Cancer. Consider the illustration: whereas the day-circles for Capricorn and Aries are traced with the correct radii for a latitude of 30°, that for Cancer, whose radius should be $h_m(\lambda = 90°) = 90° - 30° + \varepsilon = 83;35°$, is missing; or, more exactly, since the hour-lines continue until the outer scale, the latter is implicitly assumed to coincide with the day-circle of Cancer. But this can only happen if the latitude equals the obliquity. Now we can see that the "horizon", when traced until the outer scale, will meet its 60° division (because $\mathrm{Chd}\,60° = R$). One sixth of this arc will indeed corresponds to 10° of the outer scale: it seems that Najm al-Dīn wrote his inaccurate instruction *after* having made the erroneous drawing.

The quadrant presented in Ch. 71 is identical to that of Ch. 66, with the single difference that its markings – now for latitude 36° – are rotated 90° anticlockwise with respect to the latter, so that the "horizon" coincides with the arc of the quadrant (see Fig. 3.15b). Despite this mathematical identity, the second version of the quadrant bears a new name: "the quadrant with the nonagesimal (scale)".[45]

[45] This quadrant should have such a scale along its vertical side. The scale on the horizontal side that is featured in the illustrations of both manuscripts is not necessary, but it is numbered in the wrong direction.

A further refinement: a quadrant indicating the time since sunrise and the azimuth.

A further, and quite spectacular, development and refinement of the above quadrant is introduced very soon in Najm al-Dīn's treatise. Ch. 4 features a quadrant based on exactly the same geometrical design involving a 'bi-radial' coordinate system. The instrument bears two families of curves intersecting each other; they indicate the time since sunrise for each 6° and the azimuth for each 10°. It is a clever application of the geometrical design underlying the horary quadrant of Ch. 66 (and also that of Ch. 71, which is equivalent), using the same 'bi-radial' coordinates with radii $\rho_1 = h_m$ and $\rho_2 = 90 - h$, where h is the solar altitude expressed in terms of T and a, for a range of the solar declination within which these parameters are defined. The quadrant illustrated in the treatise (see Plate 18) is designed for the latitude of 36°. For latitudes within the range 30°–40° the resulting markings would also be functional and æsthetically pleasing, but for lower of larger latitudes they would become unbalanced. Because it is provided with azimuth curves, Najm al-Dīn also designated his quadrant as *al-rubʿ al-musammat.*

Based on a purely abstract geometrical construction, this instrument serves similar purposes as an astrolabic quadrant, a fact which Najm al-Dīn does not fail to mention. His motivation for inventing this quadrant was indeed to make the astrolabic quadrant superfluous. He informs us that he composed an exhaustive treatise on its use in 100 chapters, entitled "The candied sugar on the use of the azimuthal quadrant" (*al-sukkar al-munabbat bi-l-ʿamal bi-l-rubʿ al-musammat*). The legend accompanying the illustrations furthermore tells us that actual examples of Najm al-Dīn's invention had been made out of brass by *Shaykh* Muḥammad ibn al-Sāʾiḥ, otherwise unknown to us, and sold after his death.[46]

The construction of this instrument necessitates a table of $h(T,\delta)$ and $h(a,\delta)$, which is included in Ch. 4 (see Plate 9). The legend of the table says that it was compiled by means of the time-arc table (*jadāwil al-dāʾir*).

Tracing the curves for the time-arc and azimuth is a more delicate enterprise than those for the hours on the corresponding horary quadrant (Chs. 66 and 71). Nonetheless, these curves can again be approximated without noticeable error as circular arcs joining three points. Though clever in its conception, the table compiled by Najm al-Dīn omits a few entries which would have greatly facilitated the construction of the markings. Consider the curves for the time-arc. For $T = 6, 12, \ldots, 66°$, the time-arc is defined for all values of δ, and Najm al-Dīn's table provides the necessary entries of $h(T,\delta)$ at the

[46] That the maker of an instrument of Najm al-Dīn's design had already died when the latter composed his treatise suggests that a long time span had elapsed since its original invention. This remark also demonstrates that Najm al-Dīn's involvement with instrumentation was more than a purely didactical or recreational endeavour; his inventions were transmitted to others, who bestowed 'real life' on them.

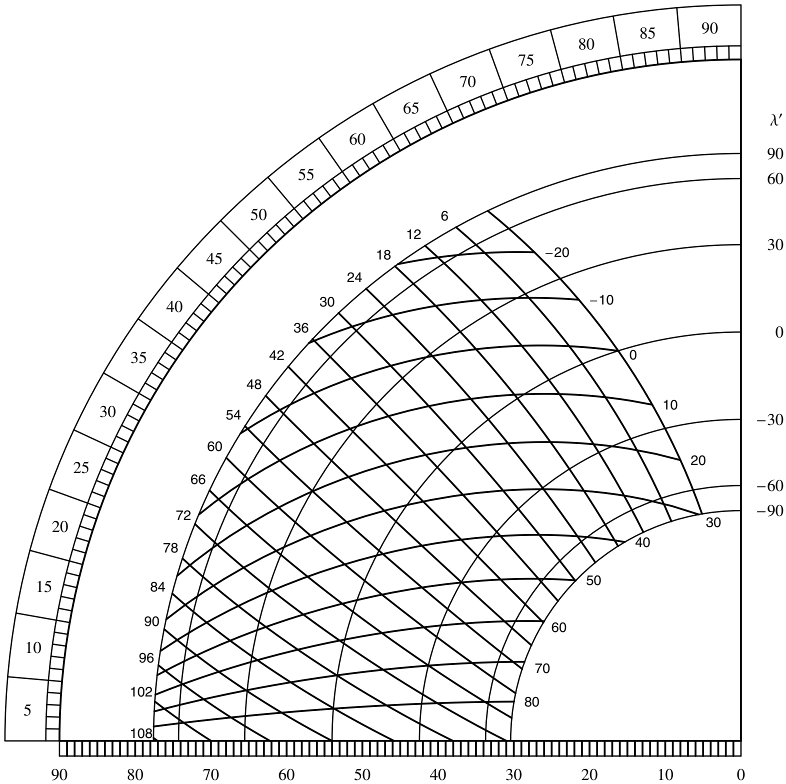


FIG. 3.16. The "candied sugar" quadrant, displaying curves for the time-arc and the azimuth

solstices and equinox. For $T > D(\phi, -\varepsilon)$, the curves are not defined at winter solstice. Since the half-daylight at winter solstice is (according to Najm al-Dīn) 71;39°,[47] the curve for $T = 72°$ will intersect the midday line very near the day-circle for winter solstice. Najm al-Dīn's table contains an entry in the column 'Capricorn' with $h(T = 71;39°) = 30;25°$, which corresponds to the meridian altitude at winter solstice; this entry cannot be used directly in the construction, but it informs the maker that the curve for $T = 72°$ will be very close to the intersection of the day-circle of Capricorn with the midday line. For $T = 78°$ the table gives the corresponding altitude for Cancer, Aries and Pisces (the latter is, however, affected by an error which would significantly compromise the construction). Only two values of $h(T)$ are given for each of

[47] The accurate value is in fact 71;30°.

the remaining curves: for $T = 84°$ and $90°$ it is given for Cancer and Aries, for $T = 96°$ for Cancer and Taurus, and for $T = 102°$ for Cancer and Gemini. Except in the case of the latter curve, which is very short, the inclusion of entries for intermediate declinations in Najm al-Dīn's table would have facilitated their construction. For the curves of $T = 78$, 84, 96 and 102°, it would also be helpful to know their intersections with the midday line: for that purpose Najm al-Dīn's table could have provided the meridian altitude h_m when $D = 78$, 84, 96 and 102°.

The situation with the azimuth curves is similar. For southern azimuths three entries of $h(a)$ are provided. For $a = 0$ the table omits the altitude at the equinox. Only two altitudes are provided for northern azimuths: a third entry for an intermediate declination would in principle be needed. The table also includes entries of h_m for different values of the ortive amplitude ψ, in order to find the intersection of the azimuth curves with the horizon (for $a = -20$, -10, 10 and 20°, the case $a = 0$ being trivial).

The copyists of both manuscripts have not been successful in drawing the markings of this instrument (see Plate 18 for a facsimile of **P**:14r). The portion UG of the day-circle for winter solstice HG (see Fig. 3.14) is erroneously divided into 13 (apparently equal) divisions, defining the extremities of the curves of time-arc on this day-circle; but a look at Fig. 3.15 reveals that the curves of $T = 6, 12, \ldots, 66$ divide this arc into 12 (unequal) divisions. Likewise, the equinoctial day-circle has one division in excess, so that the curve for $T = 96°$, instead of that for $T = 90°$, intersects this day-circle at midday. The resulting markings are inaccurate. The circular arcs approximating the curves of time-arc 'switch' their concavity at $T \approx 42.67°$; for smaller values of T the circular arcs are curved towards the bottom, and for larger values of T they are curved towards the top. For this reason the curve for $T = 42°$ can be approximated as a straight line.

3.1.3 *Altitude sundials*

Two "locust's legs" based upon the solar altitude

From a nomographic point of view, the sundials featured in Chs. 76 and 100 belong to the same category as horary quadrants. Their only particularity is that the hour-lines are represented on them *outside* of the altitude scale of the quadrant instead of inside it. In their functionality, however, they are more akin to the category of portable sundials called "locust's legs", which will be treated in the next Section. Both varieties of the sundial described by Najm al-Dīn use 'bi-angular' coordinates as on the horary quadrants mentioned above on pp. 127–130. The instrument consists of a rectangular vertical plate $ABDC$, with a gnomon set perpendicular to the plate at A (see Fig. 3.17). A point P of an hour-line is defined by the intersection of two straight lines passing through A and B and making angles $\angle BAP = \theta_1$ and $\angle ABP = \theta_2$ with respect

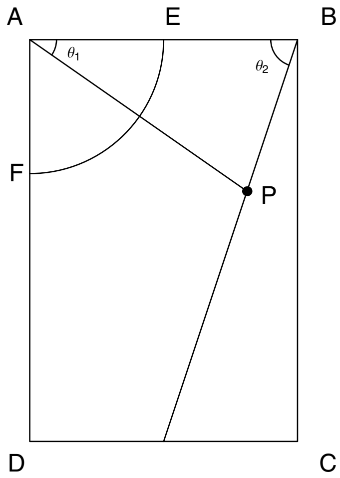


FIG. 3.17. Construction of altitude sundials with 'bi-angular' coordinates

to line AB. The altitude scale is traced on the plate as a quarter circle EF centred at A, with radius small enough that the diagonal BD will not cross it. A uniform longitude scale is then made along line CD: C will correspond to winter solstice and D to summer solstice. From each division of the scale on CD, a day-line is traced from there to point B. When the plate is hanging vertically towards the sun, the gnomon will cast a shadow on the plate, and its intersection with the appropriate day-line will indicate the time of day (see Fig. 3.18 and Plate 10). Given the design of the instrument it is not difficult to show that the angles θ_1 and θ_2 can be expressed as

$$\theta_1 = h \qquad \text{and} \qquad \theta_2 = 90^\circ - \arctan\left(\frac{90+\lambda'}{180}\,\frac{r}{R}\right).$$

A universal version of the same instrument is also featured in Ch. 76. Instead of dividing line CD according to the solar longitude, the scale is divided into 90 equal parts corresponding to the meridian altitude h_m. The hour-lines can be constructed by means of the entries of $h_i^s(h_m)$ given in Table T.11, which is based on the standard universal formula. The illustration of this sundial displays a curve for the *ʿaṣr* prayer, which can be constructed by means of the column of $h_a(h_m)$ in Table T.11 (see Fig. 3.19). The topic of representing the *ʿaṣr* on various instruments will be considered in its full generality in Section 3.5 of the present chapter.

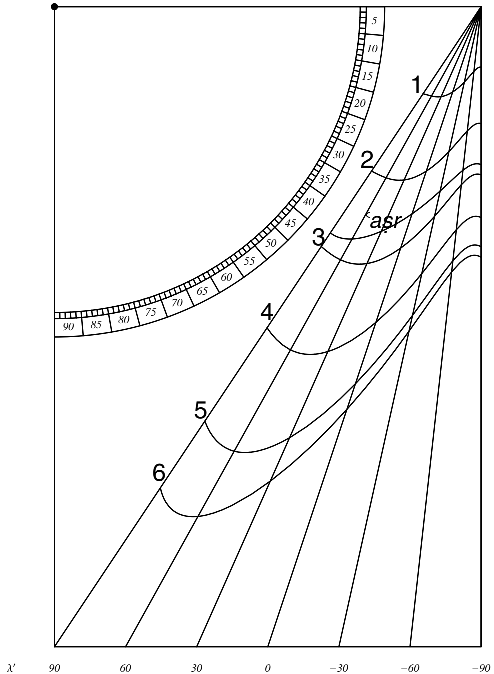


FIG. 3.18. Altitude "locust's leg" for latitude 36°

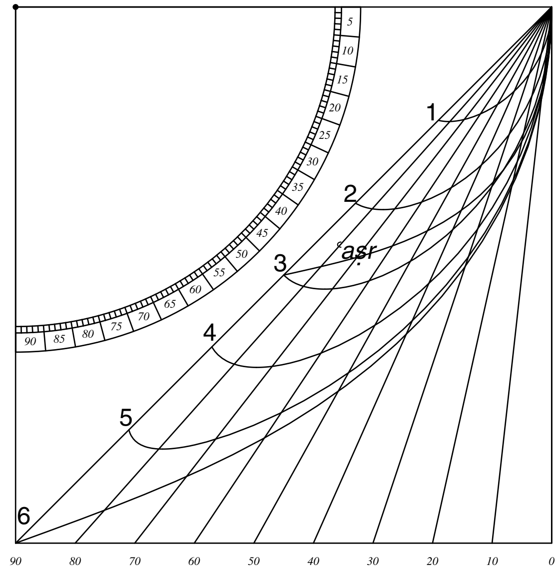


FIG. 3.19. Universal altitude "locust's leg"

An obvious variant of the instrument, not mentioned in Najm al-Dīn's treatise, would be to replace the gnomon by a plumb-line attached at *A*, and to fix a pair of sights along side *AD*, a modification which demonstrates the essential equivalence of the instrument under discussion with the horary quadrants featured earlier in this section.

A three-dimensional altitude sundial: the ring dial

The ring dial (Ch. 96) consists of a narrow cylindrical ring with horizontal axis and a hole on its upper half through which the solar rays can penetrate, and horary markings on its inner surface (see Plate 11). Najm al-Dīn designates this instrument as *sāʿāt al-damlaj*, "the bracelet dial", but we shall use in the following the standard appellation 'ring dial'. A schematic three-dimensional representation of Najm al-Dīn's ring dial is shown in Fig. 3.21.

Ring sundials are known in European sources from the late fourteenth century onward.[48] Najm al-Dīn's description appears to be the earliest extant documentation on this instrument.[49] The ring dial, designed for a particular latitude, should not be confused with the astronomical ring dial, which is universal and of a completely different design. An example of the latter with Greek inscriptions, datable to the fourth century, has been found in Philippi and documented for the first time in 1980.[50] This instrument was apparently reinvented in Central Europe, perhaps by Regiomontanus or his milieu, in the second half of the fifteenth century.[51]

The construction procedure explained in Ch. 96 can be summarised with reference to Fig. 3.20. Let *ABCD* be a circle centred at *O* representing the ring seen from one side, *A* being the top of the ring where the suspensory apparatus is attached. Counting 30° from *A* toward *D*, one obtains the position *E* of the hole. The horizontal chord *EF* is traced, whereas *F* represents the 'horizon', i.e. the projection of solar rays when the sun is on the horizon. When the sun is at the zenith, its rays will project vertically onto point *K*. With the compass centred at *E* one draws a quarter circle *FG*, *G* being located on line *EK*. This quarter circle should be graduated into 90 equal divisions, numbered from *F* to *G*, in order to correspond to the solar altitude. The day-lines are drawn on the inner surface of the ring as parallel and equidistant lines going from *F* to *K*: one edge of the ring will correspond to the day-line of winter solstice, the

[48] David King has made me aware of a short text on the ring dial (incipit: *ad faciendum anulum*), contained in a late fourteenth-century astronomical collection (MS Arras Bibliothèque municipale 688 [748]: see the brief remarks in King 2001, p. 396). This is the earliest known description of the ring dial in Europe. Zinner (1956, pp. 120–122) mentions two anonymous texts on the ring dial from the fifteenth century. A ring dial made by Humphrey Cole *ca*. 1575 is described in Ackermann 1998, pp. 44–46.

[49] al-Marrākushī's omission, however, is no proof that it did not exist before 1300.

[50] See Gounaris 1980; cf. Schaldach 1997, p. 44.

[51] See Zinner 1956, pp. 117–119. An excellent description of the principle of the instrument is in the sale catalogue of Christie's, South Kensington, 15 April 1999, lot 43.

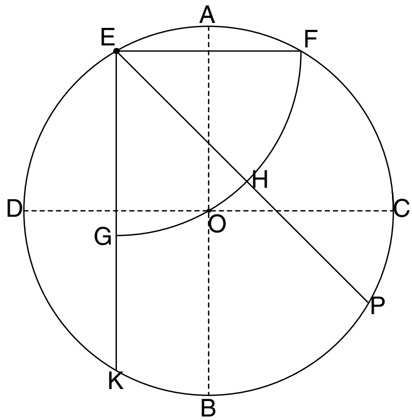


FIG. 3.20. Construction of the ring dial

other one to summer solstice. To trace the hour-lines one simply lays a ruler at E and on the altitude scale EF at the altitude of a given hour, for a given zodiacal sign: the intersection of the ruler with the inner surface of the ring (on arc FK) will allow to make mark for this hour on the corresponding day-line, and these marks are finally joined as smooth curves. The three-dimensional representation in Fig. 3.21 is accompanied at the right by a two-dimensional representation of the markings, resulting from unrolling the inner surface of the ring. It is not difficult to demonstrate that for an altitude of $h = \angle FEH$, the corresponding arc FP on the ring will measure twice that altitude (i.e., $\angle FOP = 2h$). An awareness of this property would have rendered Najm al-Dīn's construction still simpler.

To use this ring dial, one hangs it parallel to the azimuth circle of the sun: the sun spot will hence fall on the central day-line; for longitudes other than at the equinoxes, one imagines a line parallel to the width of the ring going through the sun spot, and looks at the intersection of this imaginary line with the appropriate day-line.[52]

Najm al-Dīn adds a remark about some people making supplementary hour-lines on the opposite side (i.e., on arc EDK), with a second hole at F. The utility of such a construction is not apparent. On European ring dials, however, two such holes were usually found, since the width of the ring carried day-lines for half of the zodiacal sign (positive or negative declinations):

52 Alternatively, one can design the dial in such a way that time will be indicated directly by rotating the ring about its vertical axis until the sun spot falls on the appropriate day-line: this, however, leads to a much more complicated construction of the hour-lines, which was correctly described by Andreas Schöner in his *Gnomonice* (Nuremberg, 1562): see Drecker 1925, pp. 90–91.

the markings for the other half were made on the opposite side, so that each hole was used during one half of the year. But this does not seem to be what Najm al-Dīn had in mind here.

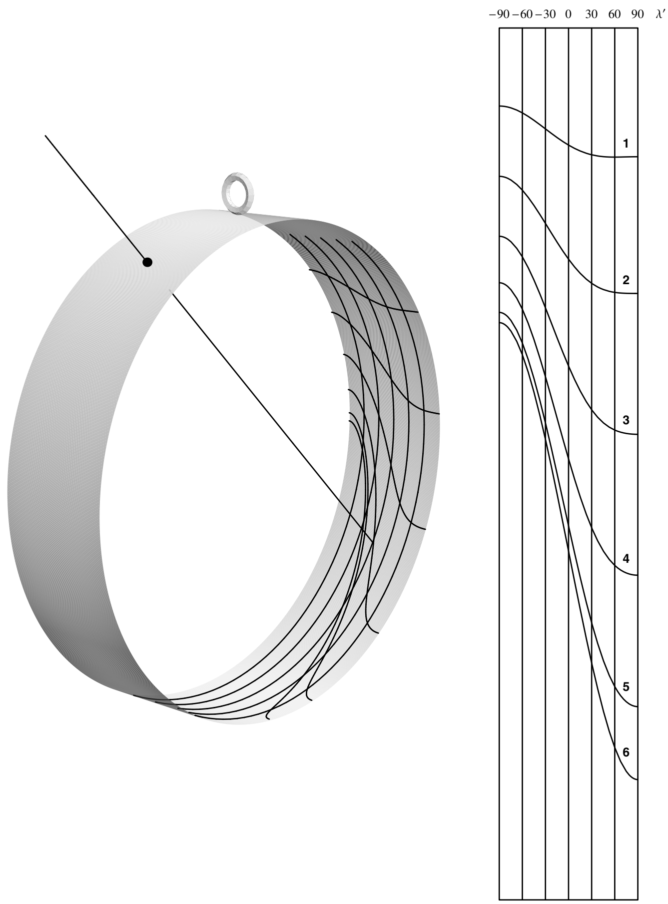


FIG. 3.21. Najm al-Dīn's ring dial

3.2 *Portable sundials displaying shadow lengths*

Portable sundials were widespread in Antiquity, as attested through some 20 archaeological findings.[53] These instruments, probably because they were so common and simple, are seldom mentioned in textual sources from the classical Islamic period (*ca.* 800–1200), yet there can be little doubt that they were well known throughout this period. First, there exist a few texts concerning them, datable to the ninth or tenth centuries.[54] Also, al-Marrākushī – the first author who discussed this category of instruments in detail – presents them as standard objects, and so does Najm al-Dīn, who presents a still wider range of such instruments than his predecessor. Many of Najm al-Dīn's instruments, however, are simple variants of known types.

This section focuses on portable sundials that tell time in terms of a shadow length, and on which the operator enters the solar longitude or the meridian altitude corresponding to the current day.[55] The next section will be devoted to universal variants of portable sundials on which the shadow length is expressed in terms of the midday shadow.

3.2.1 *Vertical dials*

The "locust's leg"

The simple sundial called "locust's leg" (*ṣāq al-jarāda* – Najm al-Dīn writes this constantly as *al-ṣāq jarāda*[56]) is a vertical rectangular flat board with straight vertical day-lines and hour-lines for the seasonal hours. It carries a horizontal gnomon, perpendicular to the board, which either can move freely within a horizontal groove, or can be fixed within one of several holes, both possibilities allowing to set the gnomon along the upper edge above the appropriate day-line. When the board is oriented towards the sun the shadow indicates the time.

There is preserved one example of such a sundial dated 554 H [= 1159/60].[57]

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[53] On antique portable sundials, see Price 1969, Buchner 1971, Schaldach 1997, pp. 40–47, 114–123. Schaldach 1997, p. 46 and Arnaldi & Schaldach 1997, p. 108 list 19 examples.

[54] See n. 75 on p. 150 on a treatise preserved in a manuscript in Istanbul containing a description of a conical sundial. Also, MS Istanbul Topkapı Ahmet III 3342, f. 74v, which I have not consulted, is said to concern "a kind of hand-held sundial" (Kennedy, Kunitzsch & Lorch 1999, p. 148).

[55] A modern astronomer's treatment of such sundials will be found in Mills 1996, which is virtually ahistorical and completely ignores the Islamic tradition – even though the author proudly and innocently introduces designs of portable dials that are Islamic in origin.

[56] See the remarks on p. 40.

[57] It was made out of brass for Nūr al-Dīn Maḥmūd ibn Zankī, successively governor of Aleppo and Damascus, by one Abū 'l-Faraj ʿĪsā, pupil of al-Qāsim ibn Hibatallāh al-Asṭurlābī (the latter being the son of the celebrated instrument-maker of Baghdad, on whom see p. 89, n. 121). See the exhaustive description in Casanova 1923, and also that in King 1993c, p. 436, with colour plate on p. 437.

The first author to mention this instrument is al-Marrākushī.[58] There is fairly good reason to believe that this kind of dial, together with the closely-related cylindrical dial (see further below), was known in the Near East in pre-Islamic and early-Islamic times.[59] The curious appellation "locust's leg" seems to be related to the form of the hour-lines, or, perhaps, more specifically to the area delimited by the fifth and sixth hour-lines, which indeed recalls the form of the stretched leg of a locust.[60] At least one dial equivalent to the "locust's leg" is attested from eighteenth-century Europe.[61]

al-Marrākushī presents two variants of this instrument; the first one, with uniform longitude scale, is for a specific latitude, and the second one, with meridian altitude scale, is universal.[62] These two basic types are presented by Najm al-Dīn in Chs. 98 and 64. A variant for a specific latitude that features a uniform meridian altitude scale (which is of course equivalent to a uniform declination scale) is also featured in Ch. 97; on this third type the markings are nevertheless based on the accurate formula. On these instruments the hour-lines can be expressed in terms of rectangular coordinates.

Uniform longitude scale; for a specific latitude. The rectangular coordinates of the hour-lines are given by

$$x \propto \lambda' \qquad (-90 \leq \lambda' \leq 90)$$
$$y \propto \mathrm{Tan}\, h_i^s .$$

[58] See n. 62 below.

[59] The famous "ham dial of Portici", found in Herculaneum and datable to the first century AD (on this dial see Delambre 1817, II, pp. 514–515; Drecker 1925, pp. 58–59; Schaldach 1997, pp. 41–42), is essentially equivalent to a "locust's leg" with fixed gnomon (on which see p. 3.2.1 below). The cylindrical sundial was also known in the Roman empire (see p. 3.2.1). The "board" (*lawḥ*) for the hours mentioned by the encyclopaedist al-Khwārizmī (*Mafātiḥ*, p. 235) is with great probability a "locust's leg". Cf. King 1999, p. 353.

[60] In a note to his translation of al-Marrākushī, J. J. Sédillot attempted an etymology of the term: "Ces deux mots signifient littéralement *jambe de la sauterelle*, dénomination qui paraît avoir quelque analogie avec celle de *sauterelle*, dont nos ouvriers se servent pour désigner une espèce d'équerre composée de deux règles mobiles, dont chacune a la forme d'une planchette, qui est celle de l'instrument dont il s'agit ici." (Sédillot, *Traité*, p. 440.) Casanova (1923, p. 286), allured by Sédillot's remark on this "nom bizarre", went still further: "Le traducteur fait très ingénieusement remarquer qu'aujourd'hui les ouvriers appellent *sauterelle* l'équerre composée de deux planchettes de cuivre mobiles autour de leur point d'attache. Si je ne me trompe, cette dénomination pittoresque vient de ce que la sauterelle présente un long corps posé presque perpendiculairement sur les pattes de derrière également très longues, d'où la comparaison avec l'équerre. Dès lors une partie de cet instrument sera naturellement le *corps de la sauterelle*, l'autre en sera la *patte* ou *jambe*. De là le nom de jambe de sauterelle donné aux plaquettes rectangulaires des astronomes". This explanation, however, operating a semantic transfer from a modern French word to a medieval Arabic expression, cannot be granted any validity.

[61] Illustrated in Mills 1996, p. 80, and Rohr 1986, p. 141.

[62] al-Marrākushī, *Jāmiʿ*, I, pp. 236–239 [*fann* 2, *qism* 2, *faṣl* 5] and pp. 239–240 [*faṣl* 6]; Sédillot, *Traité*, pp. 440-445 and 446–449. Cf. Schoy 1923, pp. 54, 55.

The height of the board is chosen equal to the vertical midday shadow at summer solstice (see Fig. 3.22a).

Declination scale, for latitude 36°. In this case the coordinates become

$$x \propto \delta \qquad (-\varepsilon \leq \delta \leq \varepsilon)$$
$$y \propto \operatorname{Tan} h_i^s .$$

The illustration in the treatise (**D**:55r) shows the vertical midday shadow at summer solstice slightly smaller than the board's height. The scale, which is labelled *between* the day-lines "30 [*sic*: read 30;25], 36, 42, 48, 54, 60, 66, 72, 77;35", is incorrect, since there should be a total of 9 day-lines instead of 10 (see Fig. 3.22b).

Finally, there is a related dial described by al-Marrākushī as occupying one face of the instrument called the 'Fazārī balance': it is equivalent with a vertical "locust's leg" with uniform longitude scale, combined with a horizontal "locust's leg" whose movable gnomon is located on the opposite side of the rectangular plate. Only the hour-lines nearest to their corresponding gnomon are drawn.[63]

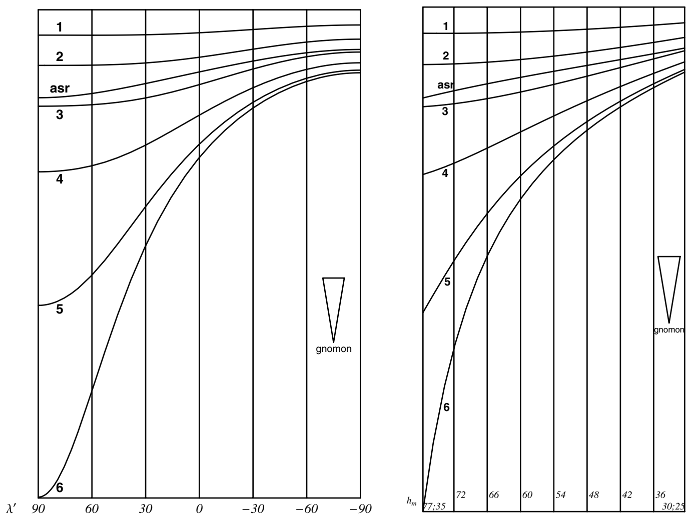
Universal "locust's leg". The universal version bears a meridian altitude scale, numbered from 0 to 90. The shadows at the hours are based on the universal approximate formula, and Ch. 64 includes a table compiled for the purpose of constructing this instrument. The coordinates of the hour-lines are defined by

$$x \propto h_m \qquad (0 \leq h_m \leq 90)$$
$$y \propto \operatorname{Tan} h_i^s .$$

Najm al-Dīn suggests that the length of the board correspond to the midday vertical shadow for $h_m = 89°$, but this would imply that the board be almost eight times longer that it is wide. A choice of $\max(h_m)$ between 83 and 86 would make more sense. For Fig. 3.23 a length of 120, corresponding to $h_m = 84;17°$, has been chosen.

Locust's leg with fixed gnomon. A drawback of these standard "locust's legs" is that their hour-lines are cluttered at winter solstice, making an accurate reading difficult. al-Marrākushī proposed a clever solution to that problem by describing a further variant on which the gnomon is fixed at the upper-left

[63] See al-Marrākushī, *Jāmiʿ*, I, pp. 245–249; Sédillot, *Traité*, pp. 458–463; the paraphrase in Delambre 1819, pp. 521–522, is less clear than the original, and the despicable comments that follow tell us more about Delambre than medieval instrumentation.



(a) Uniform longitude scale

(b) Uniform meridian altitude scale

FIG. 3.22. Two "locust's legs" for latitude 36°

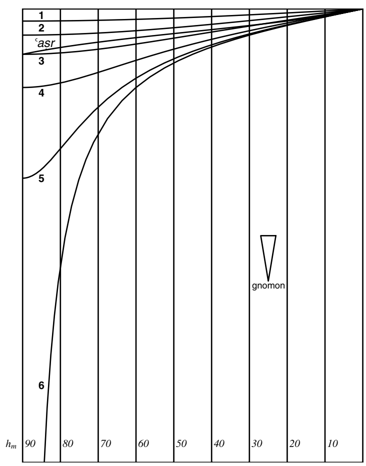


FIG. 3.23. Universal "locust's leg", with meridian altitude scale

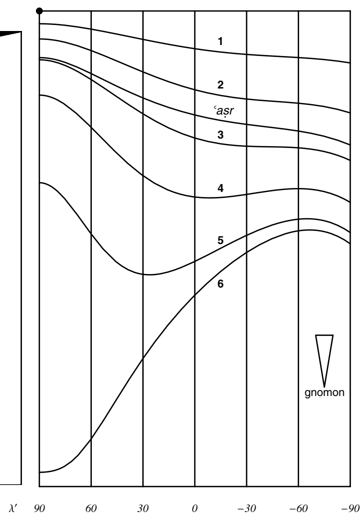


FIG. 3.24. al-Marrākushī's "locust's leg" with fixed gnomon, for latitude 30°

corner, above the day-line for summer solstice.[64] In order to read the time with this instrument the user must turn the board until the extremity of the shadow intersects the appropriate day-line.[65] The gnomon (of length 12) is fixed at the upper left corner, above the day-line of Cancer. The distance between each day-line is taken as equal to the gnomon length, so that the width between the day-lines for summer and winter solstice is six times the gnomon length (i.e., 72). To use the sundial one suspends it vertically with the *ʿilāqa* attached at the centre and rotates the board about its vertical axis until the extremity of the shadow falls exactly on the appropriate day-line.[66] This means that for each day-line, it is as though the shadow would be cast on it by a gnomon of a different length, given by

$$g'(\lambda') = 12\sqrt{1+9(1-\lambda'/90)^2} \qquad (-90^\circ \le \lambda' \le 90^\circ).$$

This sundial is illustrated in Fig. 3.24. al-Marrākushī also describes a universal version of this instrument.[67]

Cylindrical dial with movable gnomon

Only recently has it become apparent that the cylindrical dial was known in Antiquity: an example, excavated *ca.* 1900 in Este near Padua, was identified five years ago as a sundial.[68] Such a sundial was also described by Hermannus Contractus (1013–1054), monk at the Benedictine monastery of Reichenau, in a short work entitled *De horologio viatorum*, in which he explains how to construct the markings by means of a table of solar altitudes found with an astrolabe.[69] The posterior literature on this instrument is also well documented.[70]

The construction of a cylindrical dial (Ch. 106) is absolutely identical to that of the "locust's leg": one makes the same markings on a rectangular surface, wider than high, which is then rolled around the cylinder, hence defining its delimiting surface (*Mantelfläche*).[71] al-Marrākushī describes two versions

64 al-Marrākushī, *Jāmiʿ*, I, pp. 236–239 and Sédillot, *Traité*, pp. 440–444 and fig. 74.

65 This is thus equivalent to the 'ham dial' of Portici (see p. 146, n. 59). Cf. Delambre 1819, p. 520.

66 al-Marrākushī, *Jāmiʿ*, II, p. 132:18-21 [part of *fann* 3, *bāb* 1]; Sédillot, *Traité*, p. 447; cf. Delambre 1819, p. 520.

67 al-Marrākushī, *Jāmiʿ*, I, p. 239; Sédillot, *Traité*, p. 446.

68 Arnaldi & Schaldach 1997.

69 See Drecker 1925, pp. 84–85; Bergmann 1985, pp. 168–172. This work is transmitted in the manuscripts along with Hermann's treatises on the astrolabe *De mensura astrolabii* and *De utilitatibus astrolabii*: on the latter texts see Bergmann 1985, pp. 163–168.

70 See Drecker 1925, p. 85, Zinner 1956, pp. 50–51, 122–125, and Kren 1977.

71 Since the width of this surface corresponds to the circumference of the cylinder, the ratio *width*:*height* should be sufficiently large.

of this sundial – one for a particular latitude, the other universal[72] – which he calls *al-ustuwāna* ('the cylinder'). In the title of Ch. 106, however, Najm al-Dīn employs the curious expression of a "flat *conical* dial" (*mukḥul makhrūṭ musṭaḥī*), but this should be understood as a generic term referring to a 'cone with inclination zero'.[73] There follows a reference to "columns" (*aʿmida*), "small boxes" (*aḥqāq*) and "portable boxes" (*al-ʿulab al-naqqāla*), all of them with movable gnomons. While the 'columns' are simply cylindrical dials, the 'boxes' are presumably in the form of cubes, with the markings of a "locust's leg" distributed on each four vertical face. It is also conceivable that such a 'cubic' dial carries markings on three vertical faces, each provided with a longitude scale covering one third of the ecliptic, and each with a movable gnomon, possibly of different lengths in order to better distinguish the hour-lines. Najm al-Dīn's instructions for constructing the cylindrical dial are more complete than those for the "locust's leg" (Chs. 97, 98 and 64), but the idea is the same.

Conical dial with movable gnomon

The conical sundial (Ch. 90) was usually called *mukḥula* in Arabic because its shape resembles a container for eye cosmetic (*kuḥl*).[74] The earliest mention of this instrument is in an anonymous short tract, probably from ninth-century Baghdad, giving instructions for constructing it as though it were a cylindrical sundial.[75] al-Bīrūnī (*Shadows*, Ch. 15) gives a geometrical procedure for finding the altitude of a shadow cast on an inclined plane – a problem whose solution could be applied to the construction of a *mukḥula*, but he does not pursue the matter any further. He does, however, mention the *mukḥula* on one occasion, without specifying the details of its construction, in his discussion of the vertical shadow. He says that this shadow (i.e., the tangent function) "is useful in operations with hours by instruments which are raised up, like the *mukḥula* and the *sawṭ*".[76] The late tenth-century encyclopaedist Abū ʿAbd Allāh Muḥammad al-Khwārizmī lists the *mukḥula* amongst the horary instru-

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[72] al-Marrākushī, *Jāmiʿ*, pp. 231–234 [*fann* 2, *qism* 3, *faṣl* 3] and pp. 234–236 [*faṣl* 4]; Sédillot, *Traité*, pp. 433–437 and 438–440. Cf. Schoy 1923, p. 55, and Delambre 1819, p. 517.

[73] Although the first line of this chapter is partly illegible in **D**, it is possible to reconstruct its title as follows (free translation): "On the construction of the flat *mukḥul* whose coneness is such that its head has the same size as its base."

[74] See the article "al-Kuḥl" in *EI*², V, pp. 356–357.

[75] The text, entitled *ʿAmal al-mukḥula li-l-sāʿāt wa-huwa yaṣluḥu li-l-ʿumūd wa-l-ṣawṭ wa-l-ʿakkāza* "Construction of the conical sundial, which is (also) suitable for (constructing) the column, the whip and the stick", is preserved in MS Istanbul Aya Sofya 4830, f. 192r-v. It is accompanied by a table of the vertical shadow at each hour, for each zodiacal sign (one column missing) for latitude 33°. (Cf. King, *SATMI*, I, § 4.) The instructions given are indeed suitable for a cylindrical sundial, as stated in the title, but not for the truncated cone that is referred to in the text, the diameter of the upper side being five-sixths of the lower one. An edition and translation of this treatise is included in Charette & Schmidl, "Khwārizmī".

[76] al-Bīrūnī, *Shadows*, p. 99, and p. 44 of the commentary.

ments.[77]

An otherwise unknown thirteenth-century author named Ibn Yaḥyā al-Ṣiqillī wrote a short and incompetent treatise on the *mukḥula*, which has been edited by L. Cheikho, translated and analysed by E. Wiedemann and J. Würschmidt and discussed more recently by J. Livingston.[78] al-Ṣiqillī does not explain the details of the construction.[79] al-Marrākushī's account, however, provides an accurate construction method. His approach, based on a table of altitudes at the hours, involves determining graphically the length of shadows falling on the cone. He describes the construction of a conical sundial (called *makhrūṭ* – the term *mukḥula* does not appear in his treatise) for latitude 30° and a second one "for all inhabitable latitudes" based on the standard universal formula.[80]

Najm al-Dīn proceeds differently, by calculating the distance between the end of the shadow and the base of the gnomon on the surface of the cone. The contents of Ch. 90 can be summarised as follows. The conical dial consists of a truncated cone standing vertically, either with its thicker side at the bottom, sitting on a horizontal surface (called *al-makhrūṭ al-qāʿid* 'the seated cone'), or with the thicker side at the top, this being called a "suspended cone" (*al-makhrūṭ al-muʿallaq*) because it is suspended by a thread. These situations shalled be called 'upward cone' and 'reversed cone'. The inclination of the cone is defined as half the angle made at the tip of the (non-truncated) cone (see Fig. 3.25). Najm al-Dīn gives the following formula for finding this inclination i:

$$\operatorname{arcCot}\left(12\,\frac{r_2-r_1}{z}\right)=90^\circ-i,$$

where r_2 and r_1 are the radii of the base and head of the truncated cone, and z is its height.[81] A movable gnomon, perpendicular to the side of the cone, is attached near the top; on the upward cone enough space should be left above the gnomon so that a horizontal shadow will actually fall on its surface.[82]

[77] al-Khwārizmī, *Mafātiḥ*, p. 235.

[78] See Cheikho 1907; Wiedemann & Würschmidt 1916; Livingston 1972.

[79] Wiedemann's sound commentary gives a reconstruction of the instrument together with a computation of an appropriate numerical table. Livingston's paper presents interesting remarks about the relationship between al-Ṣiqillī's treatise on the *mukḥula* and a second treatise in the same Beirut manuscript, on the distance earth-sun by ʿAbbās al-Saʿīd, about whom nothing is known. Otherwise Livingston does not add anything new to the matter: the well-known analemma construction he proposes for finding the altitudes at the hours is unrelated to the conical dial itself; also, his graphical determination of the shadow lengths falling on the inclined cone is equivalent to al-Marrākushī's procedure.

[80] al-Marrākushī, *Jāmiʿ*, I, pp. 241–245 [*fann* 2, *qism* 2, *faṣl*s 7 and 8]; Sédillot, *Traité*, pp. 450–456; cf. Delambre 1819, pp. 520–521 (the formula given by Delambre is not mentioned by al-Marrākushī).

[81] The reader is actually asked to assume $z = 12$ and to measure r_2 and r_1 in terms of this scale.

[82] This orientation of the gnomon – although not clearly mentioned in the text – is implicit from the calculations.

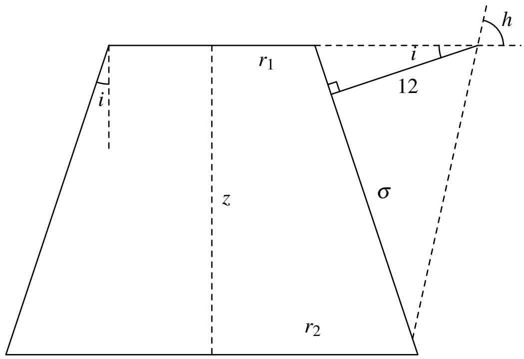

FIG. 3.25. Principle of the conical dial

The distance between the 'horizon' (i.e., the projection of horizontal shadows on the cone) and the base of the gnomon (*markaz al-shakhṣ*) is given by the (horizontal) shadow of the complement of the cone's declination (or more simply $\mathrm{Tan}\, i$). The length of the gnomon g in relation to the size of the cone has to be such that the midday shadow at summer solstice will intercept the base of the cone. This means that the side of an 'upward' cone has a length equal to the sum of $\mathrm{Tan}\, i$ and the maximal shadow; on reversed cones this length is the maximal shadow. The gnomon length will correspond to 12 units of that scale. The day-lines are drawn exactly as on the cylindrical dial.

The next step is to calculate the distance $\sigma(h)$ between the base of the gnomon and the extremity of a shadow. First assume that the cone is upward (i.e., $i \geq 0$). Calculate the quantity $90° + \bar{h} - \bar{i}$ (i.e., $90° - h + i$). If this quantity is smaller than 90°, take its horizontal shadow, which will give the distance sought for underneath the gnomon. If the quantity is larger than 90°, subtract it from 180° (which yields $90° + h - i$), and the horizontal shadow of the result will be the distance sought for above the gnomon. This is equivalent to the following formula:

$$\sigma(h) = \begin{cases} \mathrm{Cot}(90° - h + i) & \text{if } h \geq i \text{ (shadow falling underneath the gnomon),} \\ \mathrm{Cot}(90° + h - i) & \text{if } h \leq i \text{ (shadow falling above the gnomon).} \end{cases}$$

If the cone is reversed ($i < 0$) the shadow will always fall below the gnomon. In this case the above distance is given by $\mathrm{Cot}(90° - h - i)$. If $i > h$, then it is not possible for the shadow to fall on the cone.[83] Najm al-Dīn finally

[83] The choice of a gnomon perpendicular to the side makes the formula slightly simpler that if it were horizontal, in which case we would have $\sigma = g\sin h/\cos(h - i)$. The latter situation, however, has the advantage that one does not need to determine the direction of the shadow.

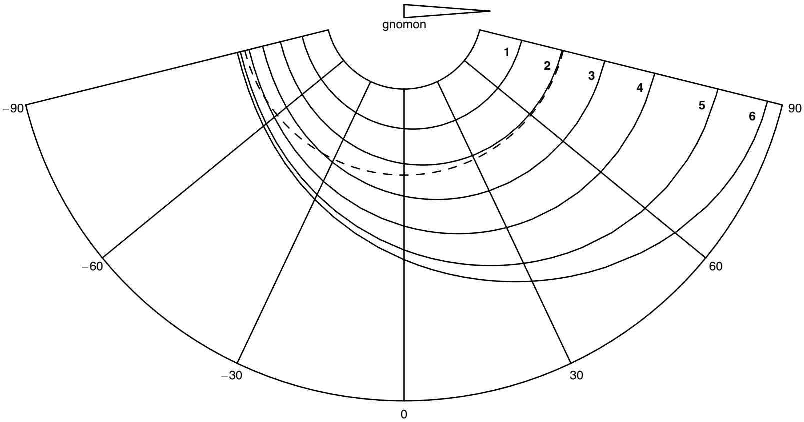

FIG. 3.26. Rolled out surface of an upward conical dial ($\phi = 36°$ and $i = 25°$); the dashed circle indicates where the gnomon should be inserted

mentions the possibility of representing altitude circles on the cone.[84]

3.2.2 *Horizontal dials using polar coordinates*

These sundials are circular horizontal plates on which the shadow length is represented in polar coordinates. A vertical gnomon stands at the centre, from which straight day-lines are radiating. The earliest known description of a sundial of this type is contained in ʿAbd al-Raḥmān al-Ṣūfī's (*fl.* tenth century) treatise in *ca*. 400 chapters on the use of the astrolabe,[85] he describes how to construct a "plate with hour-lines resembling a lemon" by means of an astrolabe.[86] On this circular plate the zodiacal signs are represented as twelve radii going from the centre of the plate (where the gnomon stands) to equidistant division of the circumference, beginning with Capricorn at the top and displayed anticlockwise. It bears six curves for the seasonal hours.

On inclined plane sundials, gnomons are likewise perpendicular to the plane of the sundial (see Section 4.3.4).

[84] Instead of simply saying that their construction is obvious, the text repeats the above formula for $\sigma(h)$, but for an upward cone it gives only the procedure for a shadow falling above the gnomon.

[85] This treatise is entitled *Kitāb al-ʿAmal bi-l-asṭurlāb*. al-Ṣūfī composed at least three treatises (or recensions thereof) on the use of the astrolabe: see Kunitzsch 1990, pp. 153–155.

[86] The construction is described in *bāb* 361, entitled *fī maʿrifat ʿamal ṣafīḥatin tujīʾu sāʿātuhā mithl atrujatin min al-asṭurlāb idhā kāna al-ẓill maʿmūlan ʿalā al-asṭurlāb* ("On the construction, by means of an astrolabe, of a plate whose hour(-lines) are set up in the form of a lemon, when the shadow (scale) is marked on the (back of the) astrolabe"). The next *bāb* (362) is devoted to its use. I have consulted al-Ṣūfī, *Kitābān* (Text 1 = MS Istanbul Topkapı Ahmet III 3509/1, 676 H, ff. 1r–261r), pp. 460–469 (construction) and pp. 469–470 (use).

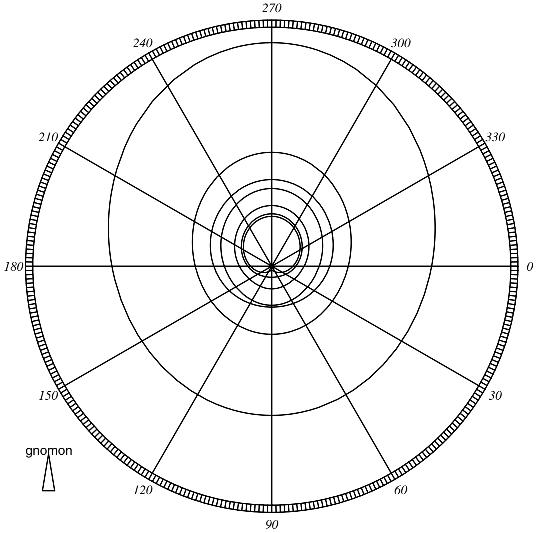

FIG. 3.27. al-Ṣūfī's 'lemon' dial

The very schematic representation of the hour-lines in the Topkapı manuscript gives a very distorted picture of the actual curves.[87] al-Ṣūfī explains how to find the shadow lengths for each hour and each zodiacal sign with the astrolabe by means of a combined use of the hour-lines on the front (yielding the altitude of each hours at a specific latitude) and the shadow square on the back. al-Ṣūfī calls this "the plate whose hour-lines are set up in the form of a lemon". The hour-lines are thus represented in polar coordinates, with

$$\rho = u_i^s = \mathrm{Cot}\, h_i^s \qquad \text{and} \qquad \theta = \lambda\,.^{88}$$

To use this sundial one needs to align the gnomon and the appropriate degree of the ecliptic towards the sun.

al-Marrākushī describes a similar sundial called *al-ḥāfir* 'the hoof', because of the shape of the hour-lines, especially that for midday.[89] On this sundial the centre of the circular longitude scale, instead of coinciding with the gnomon, is located on the diameter which joins the solstices, midway between the shortest and longest shadows at the first hour. The construction procedure is as follows. Determine these shortest and longest shadows as $r_1 = \mathrm{Cot}\, h_1^s(\delta = \varepsilon)$ and $r_2 = \mathrm{Cot}\, h_1^s(\delta = -\varepsilon)$, and find $r = (r_1 + r_2)/2$. Trace

[87] *Ibid.*, p. 469.
[88] On al-Ṣūfī's plate the angular coordinate is measured anticlockwise.
[89] al-Marrākushī, *Jāmiʿ*, I, pp. 225–229 [*fann* 2, *qism* 2, *faṣl* 1]; Sédillot, *Traité*, pp. 423–430.

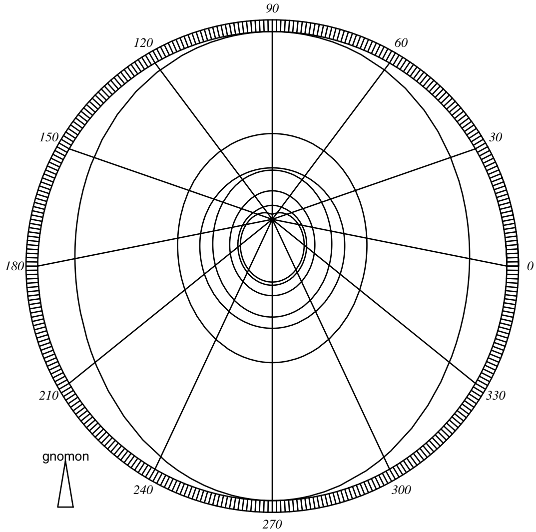

FIG. 3.28. al-Marrākushī's *ḥāfir*

a circle of radius r, and divide its circumference into twelve equal divisions. Open the compass to r_1 and place one leg on the upper extremity of the vertical diameter: the intersection of the other leg with the diameter will give the position of the gnomon. From this point trace straight lines radiating to each of the twelve divisions of the circle: these will be the day-lines, according to the configuration illustrated in Fig. 3.28.[90]

Given this geometrical construction of the day-lines, it can be shown that the hour-lines are expressed in polar coordinates with $\rho = u_i^s$ and

$$\theta(\lambda) = \arctan\left(\frac{r_1 - r + r\sin\lambda}{r\cos\lambda}\right).$$

In the older literature on the subject the *ḥāfir* was misunderstood as if its longitude scale were uniform (i.e., $\theta = \lambda$), as on al-Ṣūfī's plate.[91]

Because of the symmetry $u_i^s(\lambda) = u_i^s(180° - \lambda)$, the display can be restricted to the range of arguments $-90° \leq \lambda' \leq 90°$, by using a double scale. This

[90] In the manuscript the instrument is shown with the summer solstice below the centre; but since the sundial has no particular orientation, this detail is irrelevant.

[91] This misinterpretation first occurs in Delambre 1819, p. 516; Schoy 1913, pp. 13–17 repeated Delambre's error, as well as Wedemeyer 1916 (based on Schoy), and again Schoy 1923, pp. 57–58. Schoy 1913 contains an incorrect mathematical analysis of the hour-lines, which was corrected by Wedemeyer, whose presentation is, however, of no historical interest. I am not aware of any mention of the instrument *ḥāfir* in the subsequent literature, with the exception of King 1999, p. 299.

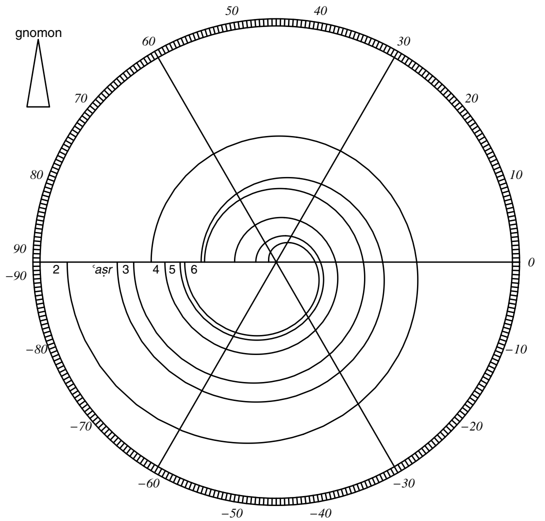

FIG. 3.29. al-Marrākushī's *ḥalazūn*

is the configuration adopted for the instrument which al-Marrākushī calls *al-ḥalazūn* 'the snail'.[92] al-Marrākushī does not describe the instrument beyond referring his reader to the accompanying illustration, from which it is clear that he defines the angular coordinate as $\theta = 2\lambda'$. The form of the hour-lines is indeed suggestive of a snail (see Fig. 3.29).

The horizontal circular dial featured in Ch. 86, erroneously called *ḥāfir* by Najm al-Dīn,[93] is in fact a universal variant of the *halazūn*, with meridian altitude scale along its circumference; only three curves are represented on it: that for the *ẓuhr*, i.e., midday, and those for the beginning and end of the *ʿaṣr* prayer. The equation of these curves, in polar coordinates, will be given by:

$$\rho_m = 12\cot h_m = 12\cot\theta/4 \quad (0 \le \theta < 2\pi),$$
$$\rho_a = 12\cot h_a = 12 + 12\cot h_m = 12 + 12\cot\theta/4,$$
$$\rho_b = 12\cot h_b = 24 + 12\cot h_m = 24 + 12\cot\theta/4.$$

Note that radius of the plate is limited to 60 units (with gnomon length 12); also the meridian altitude scale is numbered anticlockwise. On Fig. 3.30 I have added to the above three curves also those of the seasonal hours (dashed).

[92] al-Marrākushī, *Jāmiʿ*, I, pp. 229–230; Sédillot, *Traité*, p. 430.

[93] Compare the following statement by al-Marrākushī: "Some people call the *halazūn* a *ḥāfir*, which is incorrect. It is called *ḥāfir* because its shape resembles a hoof, while the *halazūn* is different." al-Marrākushī, *Jāmiʿ*, I, p. 230:2-3; Sédillot, *Traité*, p. 430.

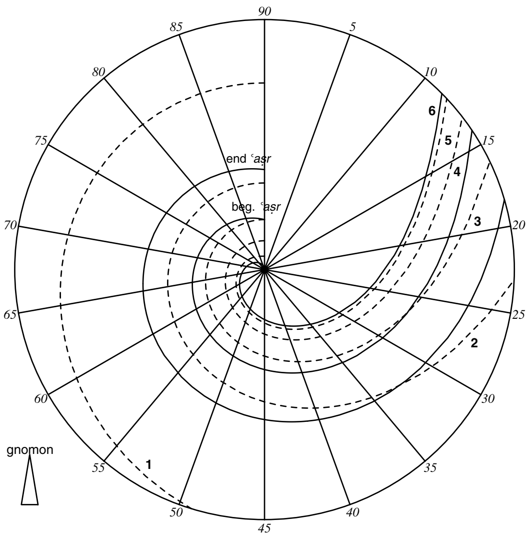

FIG. 3.30. Najm al-Dīn's universal *halazūn* (with hour-lines 1–5 added)

In Ch. 63 a similar universal dial is described, this time with curves for the seasonal hours and the beginning of the *ʿaṣr*. On the illustration the graph is limited to a quadrant, with the angular coordinate $\theta = h_m$. Najm al-Dīn notes that a representation on a whole circle is also usual: this is equivalent to the dial featured in Ch. 86. There is a problem with the scale on the illustration of Ch. 63 in both manuscripts, and only hour-lines 2–6 have been traced. On Fig. 3.31 the same scale as in Fig. 3.30 has been chosen (namely, radius 60 and gnomon length 12), so that all hour-lines can be represented on the quadrant.

Najm al-Dīn's ḥāfir *dial with circular* ʿaṣr *curve*

The *ḥāfir* with the *ẓuhr* and *ʿaṣr* presented in Ch. 88 provides another example of a scale defined in reverse from the particular shape assigned to an otherwise irregular curve. In this case, the usually 'hoof-shaped' curve for the *ʿaṣr* is drawn as a perfect circle, with eccentric gnomon.

The construction can be explained with reference to Fig. 3.32. Draw a circle centred at O with vertical diameter AB, which should measure the sum of the *ʿaṣr* shadows at both solstices; with a gnomon of length 12, this gives:

$$\widehat{AB} = \left(\operatorname{Cot}\min(h_a) + \operatorname{Cot}\max(h_a)\right) = 12\left(2 + \cot(\bar{\phi} - \varepsilon) + \cot(\bar{\phi} + \varepsilon)\right) .$$

Find C on line AB so that AC measures the *ʿaṣr* shadow at winter solstice (so that $\widehat{CB}$ will measure the same quantity at summer solstice). With the

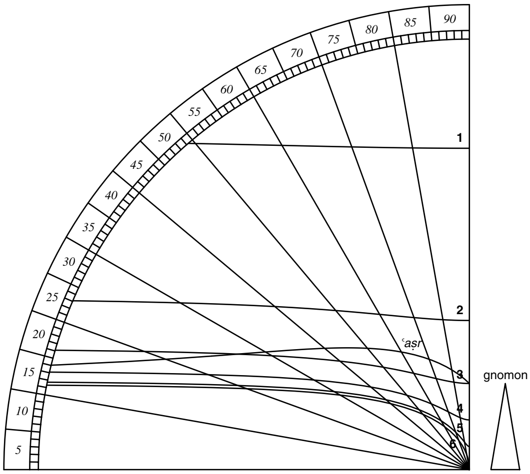

FIG. 3.31. The same markings restricted to a quadrant

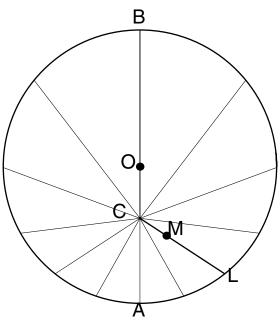

FIG. 3.32. Construction procedure in Ch. 88

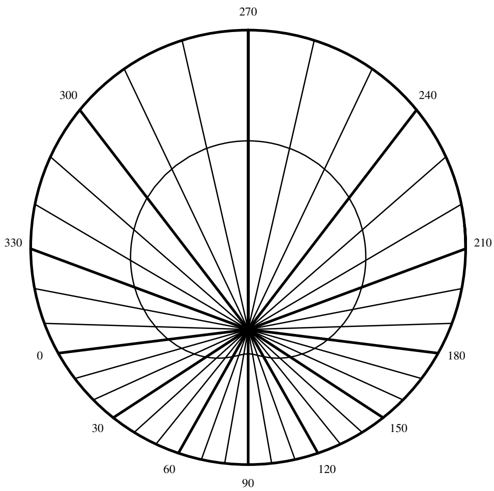

FIG. 3.33. The *ḥāfir* with circular *ʿaṣr* curve

compass at C open it to the ʿ*aṣr* shadow at each zodiacal sign, and mark point L on the outer circle; trace line CL, which will represent the corresponding day-line. Once all zodiacal lines are traced, open the compass to the gnomon length. Put one leg on the intersection of each zodiacal line with the outer circle and the other one where it meets the corresponding zodiacal line, and find point M on line CL so that $\widehat{LM} = 12$. Do this for all signs and join these marks. The resulting figure will not be a circle, despite the misleading announcement in the title of Ch. 88. But the last sentence lets us realise that Najm al-Dīn had some doubts about the possibility of tracing the curve of the midday shadow as a complete circle, because he also leaves open the option of tracing it 'pointwise'. However, the figure in the manuscript has this curve drawn as a circle. The correct graph is shown in Fig. 3.33.

The angular function underlying the longitude scale, instead of being a linear function of the longitude as on the standard *ḥāfir*, is now given by:

$$\theta(\lambda) = \arcsin\left\{\frac{r_1 r_2 - (12 + 12\cot h_m(\lambda))^2}{(r_2 - r_1)(12 + 12\cot h_m(\lambda))}\right\},$$

where

$$r_1 = \widehat{AC} = 12 + 12\cot(\bar{\phi} + \varepsilon) \quad \text{and} \quad r_2 = \widehat{CB} = 12 + 12\cot(\bar{\phi} - \varepsilon).$$

On the above diagram the thick lines correspond to those drawn in the manuscript. Most angles for the zodiacal signs are incorrect in the illustration, and in one case the symmetry with respect to the vertical axis is not respected.

The ḥāfir *and* ḥalazūn *in Renaissance Europe and Safavid Persia*

Several dials from late sixteenth-century Prague (and possibly also Nuremberg) are identical in conception to the Islamic dials described above; of course they display the equal hours instead of the seasonal ones. A horizontal '*ḥāfir*' dated 1587 is preserved in the Germanisches Nationalmuseum in Nuremberg;[94] since its angular coordinate is $\theta = \lambda$, it is thus equivalent to al-Ṣūfī's horizontal dial. Four types of *vertical* dials signed by Erasmus Habermel (instrument-maker at the court of Rudolf II in Prague, d. 1606) also feature polar coordinates.The first type is equivalent to al-Ṣūfī's dial (with $\rho = \mathrm{Tan}\, h_i^e$ and $\theta = \lambda$),[95] and the second one to al-Marrākushī's *ḥalazūn* (with

[94] Inv. no. WI 1805; square plate 135×135 mm, unsigned. See Zinner 1956, p. 334 (where the remark "Der Schattenstab steht zugleich im Brennpunkt der Kegelschnitte der Stundenkurven" is meaningless). Photos of this dial are in the Ernst-Zinner-Archiv of the Institut für Geschichte der Naturwissenschaften, Frankfurt am Main.

[95] Four examples of the first type signed by or attributable to Habermel are known to me: Vienna, Kunsthistorisches Museum, inv. no. 726, signed, dated 1586 (see Zinner 1956, p. 333 and Tafel 38b), and a second one, undated, inv. no. 737 (Zinner 1956, p. 333 – photograph in the Ernst-Zinner-Archiv); Frankfurt, Historisches Museum, inv. no. X 852, signed, dated 1589 (see Glasemann 1999, pp. 107–108, no. 57). Nuremberg, Germanisches Nationalmuseum, inv. no. WI 1809 (Zinner 1956, p. 333 – photograph in the Ernst-Zinner-Archiv).

$\rho = \mathrm{Tan}\, h_i^e$ and $\theta = 2\lambda$).[96] Another dial of the first type, anonymous and probably earlier than Habermel's productions by some decades, is also preserved in Nuremberg.[97] On this dial the midday curve is traced as a perfect *circle*, thus defining the longitude scale in reverse (compare Najm al-Dīn's *ḥāfir* with circular *ʿaṣr* curve described above). On the third type the gnomon stands at the circumference of the circular dial, whose radius corresponds to the midday vertical shadow at summer solstice. The hour-lines are thus represented by the coordinates $\rho = \mathrm{Tan}(90° - \phi + \varepsilon) - \mathrm{Tan}(h_i^e)$ and $\theta = \lambda$.[98] The fourth type is equivalent to the latter, with $\theta = 2\lambda$ as on the second type.[99]

A vertical sundial identical to Habermel's first type (but for seasonal hours) was devised by the Safavid scientist Qāsim ʿAlī Qāyinī[100] (*fl.* Isfahan, *ca.* 1685), and bore the name *lawḥ al-anwār*.[101] It is possible that Qāsim took inspiration from European dials which European traders and travellers might have brought to Isfahan.

3.3 *Universal sundials based on the midday shadow*

The universal sundials described so far bear a meridian altitude scale; in other words, their construction is based on a table of the horizontal or vertical

[96] At least two examples of the second type are recorded: the first one, formerly in the collection of Henri Michel, Brussels (see Zinner 1956, p. 333), is now probably in the Museum for History of Science in Oxford; the second one is in Frankfurt, Historisches Museum, inv. no. X 854, undated (see Glasemann 1999, pp. 108–109, no. 58).

[97] Germanisches Nationalmuseum, inv. no. WI 24 (see *Focus Behaim Globus*, II, pp. 613-614) – the underlying latitude is *ca.* 49°20′.

[98] The earliest example of this type is signed by Gerhard Emmoser and dated 1571; it is preserved in Nuremberg, Germanisches Nationalmuseum, inv. no. WI 1803 (see Zinner 1956, p. 304 and Tafel 38a); Examples signed by or attributable to Habermel are the following: Frankfurt, Historisches Museum, inv. no. X 853, signed, undated (see Glasemann 1999, pp. 109–110, no. 59); Prague, Technical Museum inv. no. 142, unsigned, undated, made for Franciscus de Paduanis (see Zinner 1956, p. 336 – photograph in the Ernst-Zinner-Archiv); Utrecht University Museum, inv. no. UM 302, unsigned, undated, with different coat of arms than on the previous dial (see van Cittert 1954, p. 21 and plate XIV; the instrument is unhappily described in this catalogue as an "astrological disc", and the curves are mistakenly thought to be for hour conversions). Zinner also lists an example in Traunstein, Sammlung Ehrensperger no. 14, unsigned, undated, "Wahrscheinlich in Habermels Werkstatt entstanden" (Zinner 1956, 13th item on p. 345 – photograph in the Ernst-Zinner-Archiv). NB: The Prague and Utrecht dials display curves for the equal *and* seasonal hours (the latter being dashed).

[99] Only one dial of this type is known; it is preserved in Munich, Historisches Museum, inv. no. 1693, unsigned, undated (not listed in Zinner 1956 – photograph in the Ernst-Zinner-Archiv); on this piece the labelling of the zodiacal signs on the outer scale is incorrect.

[100] On this individual, see King 1999, pp. 264, 266–268.

[101] Qāsim ʿAlī's treatise in 14 chapters on the construction and use of this instrument, entitled *Matlaʿa dar maʿrifat-i awqāt-i ṣalāt va samt-i qibla va sāʿāt va daqāyiq zamānī va ghayr dhalika*, is preserved in MS Tehran Majlis 6266/5, pp. 57–93; the dial is illustrated on p. 61. Compare the remark in King 1999, p. 299.

shadows computed with the standard universal formula, i.e., with entries of $\operatorname{Cot} h_i^s(h_m)$ or $\operatorname{Tan} h_i^s(h_m)$. This Section considers universal sundials that bear a scale of the midday shadow. The horizontal and vertical shadows at midday are given by $u_m = \operatorname{Cot} h_m$ and $v_m = \operatorname{Tan} h_m$. From the universal formula $h_i^s(h_m)$ a formula for the function $u_i^s(u_m)$ can be derived. Using the trigonometric identities

$$\cot(\arcsin x) = \sqrt{1-x^2}/x \qquad \text{and} \qquad \sin(\operatorname{arccot} y) = 1/\sqrt{1+y^2},$$

we find

$$\begin{aligned} h_i^s &= \arcsin\{\sin(15\,i^\circ)\ \sin h_m\} \\ &= \arcsin\{\sin(15\,i^\circ)\ \sin(\operatorname{arccot}(u_m/12))\} \\ &= \arcsin\left\{\frac{\sin(15\,i^\circ)}{\sqrt{1+(u_m/12)^2}}\right\}, \end{aligned}$$

so that the horizontal shadow at the seasonal hours is given in terms of the midday shadow by

$$u_i^s(u_m) = \operatorname{Cot} h_i^s = 12\cot\left\{\arcsin\left(\frac{\sin(15\,i^\circ)}{\sqrt{1+(u_m/12)^2}}\right)\right\} \tag{3.1}$$

$$= \frac{12}{\sin(15\,i^\circ)}\sqrt{1-\frac{\sin^2(15\,i^\circ)}{1+(u_m/12)^2}}\,\sqrt{1+(\frac{u_m}{12})^2} = \sqrt{\frac{12^2+u_m^2}{\sin^2(15\,i^\circ)}-12^2}. \tag{3.2}$$

The formula for $v(v_m)$ is easily found by substituting in the above u and u_m by $v/144$ and $v_m/144$.

3.3.1 *Universal* ḥalazūn

al-Marrākushī presents a version of his *ḥalazūn* with angular coordinate $\theta \propto u_m$.[102] He divides the circumference of an imaginary circle into 37 equal parts, for $u_m = 0, 1, \ldots, 36$. This configuration leads to the following polar coordinates:

$$\theta = \frac{2\pi(u_m+1)}{37} \qquad \text{and} \qquad \rho = u_i^s(u_m) \qquad (0 \le u_m \le 36),$$

hence the polar equation of the hour-lines becomes:

$$\rho(\theta) = \sqrt{\frac{12^2+\left(\frac{37\,\theta}{2\pi}-1\right)^2}{\sin^2(15\,i^\circ)}-12^2} \qquad (2\pi/37 \le \theta \le 2\pi).$$

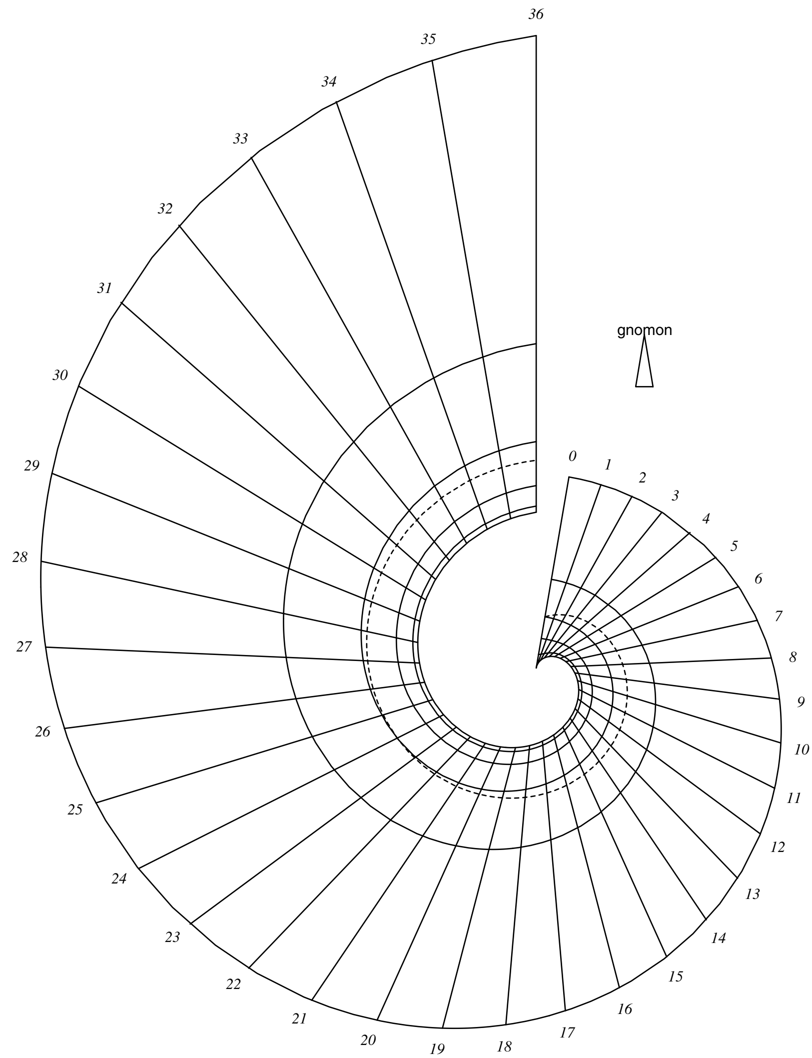

FIG. 3.34. al-Marrākushī's *ḥalazūn* in terms of the midday shadow (the outermost curve is for the first hour, the innermost one for midday, the dashed one for the ʿ*aṣr*)

When $i = 6$, this simplifies to

$$\rho(\theta) = \frac{37\,\theta}{2\pi} - 1\,,$$

which is an Archimedean spiral.[103] The instrument is illustrated in Fig. 3.34.

3.3.2 *Universal rectangular sundials on the Fazārī balance*

The multi-purpose ‘ruler’ called the “Fazārī balance” (*al-mīzān al-Fazārī*) consists of a rectangular parallelepiped with various tables, sundials and graphs drawn on its four rectangular faces.[104] Here we shall only concern ourselves with al-Marrākushī’s and Najm al-Dīn’s universal sundials based on the midday shadow which are intended to be displayed on one of the faces of this instrument. An elegant nomogram is displayed on the third face of the Fazārī balance described by al-Marrākushī. It combines adjacent plots in Cartesian coordinates of the functions $u_i^s(u_m)$, $v_i^s(u_m)$ and $v_i^s(v_m)$, all within the range $0 \leq u_m \leq 12$ and $0 \leq v_m \leq 12$.[105] This principle of this nomogram should be obvious by considering Fig. 3.35.

al-Marrākushī also mentions in passing the possibility of marking the first face of the Fazārī balance with a double universal sundial of the “locust’s leg” type. The width of the dial is divided into 36 equal parts, and forms a midday shadow scale. The dial is provided with two gnomons, one at each extremity of the dial, and movable along its width. It is intended to be used as a horizontal “locust’s leg” with one gnomon, and as a vertical one with the second one.[106]

Najm al-Dīn devotes Ch. 62 to a universal sundial also intended for one face of the Fazārī balance. On his version, the hour-lines are represented by means of a ‘mixed’ coordinate system. The width of the rectangular face is also divided into 36 equal parts, and equidistant lines parallel to the length of the dial are traced. The distance of each parallel line to one side of the dial corresponds to a midday shadow. The gnomon of length 12 is located at the centre of the line corresponding to $u_m = 0$. To construct the hour-lines, the compass is opened to the shadow lengths $u_i^s(u_m)$, and one leg is placed at the base of the gnomon; two marks are made on both sides at the intersections of the other leg with the appropriate line of u_m. If the base of the gnomon is the origin of the coordinate system and the y-axis is perpendicular to the length

102 al-Marrākushī, *Jāmiʿ*, I, pp. 230–231 [*fann* 2, *qism* 2, *faṣl* 2]; Sédillot, *Traité*, pp. 430–432.

103 The curve for the *ʿaṣr*, with $\rho(\theta) = 12 + \frac{37\theta}{2\pi} - 1$, is also an Archimedean spiral.

104 On this instrument see further Section 6.2.

105 al-Marrākushī, *Jāmiʿ*, I, pp. 251:6–254:1 [part of *fann* 2, *qism* 2, *faṣl* 9]; Sédillot, *Traité*, pp. 465–469.

106 The version for a specific latitude of this sundial has been mentioned on p. 147 above.

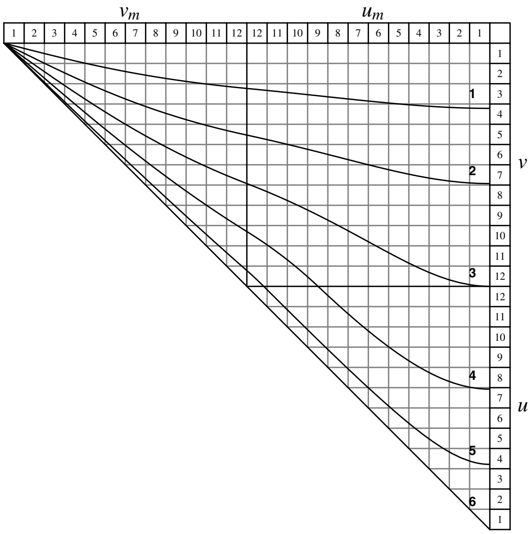

FIG. 3.35. al-Marrākushī's nomogram for $v_i^s(v_m)$, $v_i^s(u_m)$ and $u_i^s(u_m)$

of the dial, the coordinates y and ρ defining the hour-lines are as follows:

$$y = u_m \qquad \text{and} \qquad \rho = u_i^s(u_m)\,.$$

Using formula 3.1 for $u_i^s(u_m)$ it is not difficult to show that coordinate $x = -\sqrt{\rho^2 - y^2} = \sqrt{u_i^{s2} - {u_m}^2}$ can be simplified to yield

$$x = -\sqrt{12^2 + {u_m}^2}\ \cot(15^\circ\, i)\,.$$

The hour-lines are thus half-hyperbolæ defined by the following equation, where the x-axis coincides with day-line $u_m = 0$, and the y-axis with the meridian (see Fig. 3.36):

$$\frac{x^2}{(12\,a)^2} - \frac{y^2}{12^2} = 1 \quad \text{where } a = \cot\left(\frac{i\,\pi}{12}\right) \quad \text{and} \quad i = 1,2,\ldots,5.$$

The *ʿaṣr* curve is a section of a parabola, defined by the equation

$$x = \sqrt{24y + 12^2} \qquad (0 \le y \le 36).$$

3.3.3 *Universal sundial on a lunule, with straight hour-lines*

Najm al-Dīn's instructions on how to construct this instrument (Ch. 61) are somewhat garbled. The construction described below is an attempt at reconstructing the original instrument.

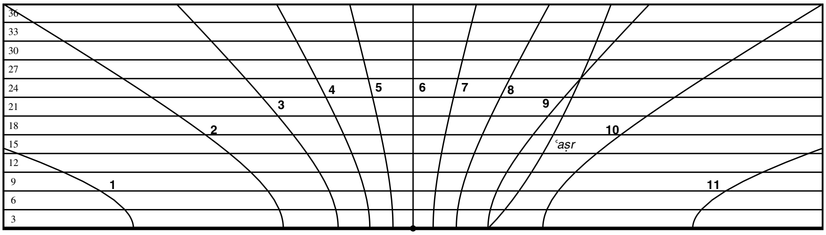

FIG. 3.36. Najm al-Dīn's rectangular universal sundial

The surface of this universal horizontal sundial is a 'lunule'. The circumference of the outer arc of the lunule is $\frac{4\pi}{3}$, the inner arc having the same radius as the outer one, so that the lunule corresponds to a circle, with one third of its circumference being folded over. The radius of the lunule is in principle arbitrary, but Najm al-Dīn defines it as the shadow at the second hour when the midday shadow is 36 (with a gnomon of length 12), so that the second and tenth hour-lines will intersect the circumference. This definition leads to a radius of *ca*. 75.[107] The gnomon is located at the intersection of the vertical diameter (the meridian line) with the lower arc. Assume that the day-line for $u_m = 36$ is a horizontal straight line, and that the day-line for $u_m = 0$ coincides with the lower arc of the lunule. Also assume that the day-lines are to be traced as straight lines, which is confirmed by their shape on the illustration (see Plate 12) and by the instructions in the text. A reconstruction of the instrument is illustrated on Fig. 3.37.

In Najm al-Dīn's treatise, the shadow scale along the meridian is *non-uniform*; moreover, the day-lines are straight for $u_m \geq 18$, and look like circular arcs for $u_m < 18$. With such a construction it is possible to construct hour-lines as irregular 'curves' or as piecewise linear segments. But using the sundial gets arduous since, in order to compensate for the non-uniformity of the meridian scale, the gnomon must be varied in length for different values of the midday shadow. This can hardly correspond to the original instrument.

In its original version, this instrument surely featured *straight* hour-lines, which is roughly what the illustration in the manuscript suggests. The 'day-lines' for $u_m = 6, 12, \ldots, 30$ thus become complicated curves, constructed by joining the markings made on those hour-lines for the different values of the shadow in terms of the midday shadow.

To use this sundial one must rotate it until the shadow falls on the 'day-line' corresponding to the computed or observed midday shadow for the day.

[107] Actually $u_2^s(36) = 74;56$.

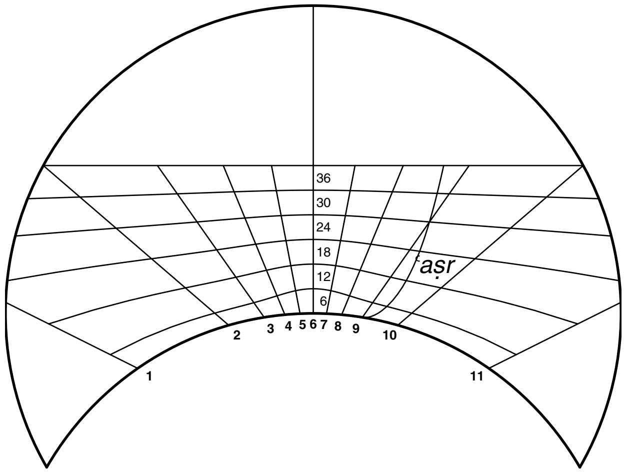

FIG. 3.37. Universal 'lunule' dial

3.4 *Azimuthal dials*

Azimuthal dials are horizontal plates aligned with the cardinal directions; they carry a vertical gnomon of arbitrary length at the centre. Such dials indicate time by means of the direction of the shadow: the user simply needs to identify the intersection of the shadow with the appropriate day-circle and its position with respect to the hour-lines will indicate the time. It is traditionally thought that azimuthal dials were invented in Renaissance Europe.[108] We have seen in Chapter 2 that an astrolabic instrument known in thirteenth-century Egypt, namely the *musātira*, can serve as the basis for an azimuthal dial. I am not aware, however, of any Muslim authors who explicitly considered this possibility.[109] Yet Najm al-Dīn's treatise does contain two chapters devoted to authentic azimuthal dials, which constitute the earliest known descriptions of such dials.[110]

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[108] On azimuthal dials, see Drecker 1925, pp. 98–102, and Zinner 1956, pp. 128–130.

[109] It is nevertheless possible to use the *musātira* in a functionally equivalent way, by laying it on a horizontal surface and aligning it with the cardinal directions. The alidade on the front can then be aligned so that the shadow of one sight falls exactly over the alidade: the intersection of the alidade with the appropriate day-circle will tell the time of day. This alternative possibility for finding time with this instrument is not mentioned by al-Marrākushī; however, he does explain how to find the cardinal directions with it (see p. 89, n. 124), and even adds a chapter on how to determine the time since sunrise when the cardinal directions and the altitude are known but not the solar longitude (al-Marrākushī, *Jāmiʿ*, II, p. 253:4–13 [*fann* 3, *bāb* 10, *faṣl* 11]).

[110] There exists a description of a *universal* azimuthal dial in the last chapter of an Andalusi treatise on mechanics by Ibn Khalaf al-Murādī, whose description was edited and analysed in

In Chs. 84 and 85 Najm al-Dīn describes two azimuthal dials displaying curves of the time since sunrise on the eastern half of the plate, and the time until sunset on the western half. His instructions are not very clear, especially in Ch. 84, but the overall procedure he gives is sound. Yet in the graphical realisation of the instruments he apparently made unreflected assumptions which led him to seriously impair their design. Before considering the diagrams in the manuscript, we shall first explain the mathematical principle of azimuthal dials.

We need a formula expressing the azimuth (measured from the east or west) in terms of the hour-angle (and hence of the time-arc). The representation of the curves of the time-arc T will involve polar coordinates, where ρ is some function of the solar longitude, and θ is the azimuth:

$$a(T,\phi,\delta) = \arcsin\left(\frac{\sin h\ \sin\phi - \sin\delta}{\cos h\ \cos\phi}\right),$$

$$\text{with} \qquad h = \arcsin\{\sin\phi\ \sin\delta + \cos\phi\ \cos\delta\ \cos(D-T)\}$$

$$\text{and} \qquad D = \arccos(-\tan\phi\ \tan\delta)$$

The radial coordinate ρ can be expressed in various ways. In Ch. 85 Najm al-Dīn considers two possibilities: the radius of the plate is divided into seven parts, either equal or unequal. In the first case the concentric day-circles are equidistant. The second case is not explained at all, but to judge from the illustration we can assume the radii to be proportional to the solar declination.[111] A third case is presented in Ch. 85, where the radii of the day-circles are defined by stereographic projection of the associated declination circles, as on a northern astrolabe. The constructions proposed by Najm al-Dīn are equivalent to the following expressions for the radial coordinate:

1. $\rho = \frac{R}{7}(4+\frac{3\lambda}{90}) \quad -90 \leq \lambda \leq 90$ (see Fig. 3.38a)
2. $\rho = \frac{R}{7}(4+\frac{3\delta}{\varepsilon}) \quad -\varepsilon \leq \lambda \leq \varepsilon$ (see Fig. 3.38b)
3. $\rho = R_E \tan\left(\frac{90-\delta(\lambda)}{2}\right) \quad -90 \leq \lambda \leq 90$ (see Fig. 3.38c)

Azimuth dials corresponding to the above three definitions of the day-circles are illustrated in Fig. 3.38. They bear curves, as on Najm al-Dīn's illustration, for each 15° (i.e., one equal hour) of the time since sunrise or until sunset. On

details in Casulleras 1996. The design of this sundial, however, is extremely crude, if not absurd; Casulleras's hypothesis is that it represents the adaptation of a sundial that was originally set in the plane of the equator.

[111] A European azimuthal dial made *ca.* 1575 with radii proportional to the declination is preserved in the Museum for History of Science in Oxford: see Michel 1966, p. 161 and pl. 71.

the dials described in Ch. 84 the innermost day-circle is Capricorn, whereas in Ch. 85 the situation is reversed, with Cancer being the innermost day-circle.

At the end of Ch. 84 there is a laconic remark about the day-circles of the *musātira* being the best possibility: this proves that the use of the horizontal stereographic projection for an azimuthal sundial was indeed considered by Muslim astronomers prior to Najm al-Dīn (who does not present this idea as new).

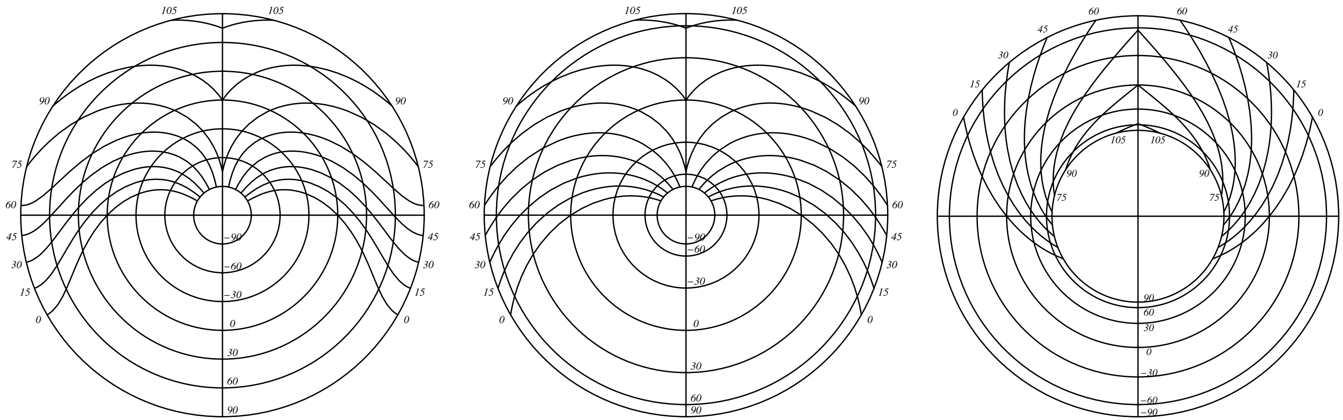
The errors made in the diagrams of Chs. 84 and 85 are of interest, because they reveal how the author's temerity in dealing with complex mathematical instruments sometimes turned into foolhardiness.[112] He seems to have assumed that the markings *on both halves* could be connected with circular arcs, as if the underlying curves were continuous. But obviously the time elapsed since sunrise $T = D - t$ is a not the same as the time left until sunset $2D - T = D + t$, and their respective curves on both halves, although they meet on the meridian, do not connect smoothly (see Fig. 3.38). Only three construction points were marked on both sides of the plate, which were then joined as circular arcs: as a consequence, the curves are erroneous, especially on the dial featured in Ch. 84.[113]

A rudimentary shadow instrument

A most simple type of shadow instrument is presented by in Ch. 83. It is discussed here because it is 'functionally' related to the azimuthal dial. It consists of a horizontal disk with vertical gnomon at the middle. Its only markings are azimuthal lines – which are simply radii drawn at each 10° – and altitude circles, that is, concentric circles with radii $\rho(h) = \mathrm{Cot}(h)$, drawn for $90^\circ > h > 10^\circ$. Even though the instrument is universal, Najm al-Dīn limits the markings to the domain of the azimuth which is valid at the latitude of the construction: the southernmost azimuth lines will correspond to the maximal rising amplitude (on the illustration this is given as *ca.* 30°, which corresponds to a latitude of *ca.* 36°). One can also trace the circles of shadow, he adds, which are equidistant. But this would make the markings on this simple instrument too crowded.

[112] It is hardly possible that these errors be solely due to the copyists, and I therefore assume that Najm al-Dīn's original drawings were already problematic.

[113] The illustration of Ch. 85 (together with Ch. 86, that is, **D**:49v–50r) was featured in the exhibition catalogue *Europa und der Orient*, p. 654 to illustrate Muslim scientific achievements in instrumentation.



(a) First version of Ch. 84 (not illustrated)

(b) Interpretation of the second version of Ch. 84

(c) Version of Ch. 85

FIG. 3.38. Najm al-Dīn's azimuthal dials

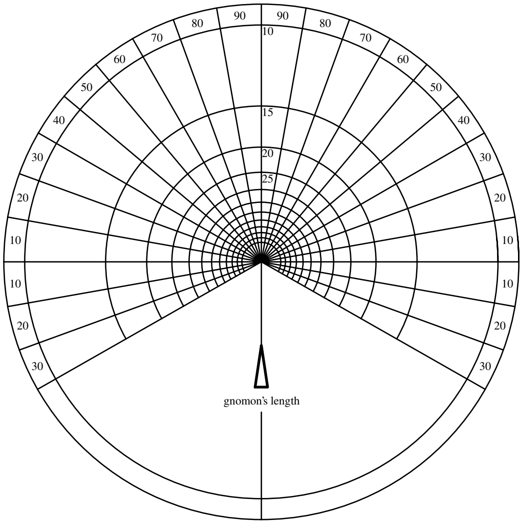


FIG. 3.39. Horizontal sundial for finding the solar altitude and the azimuth

3.5 *Representing the* ʿaṣr *on various instruments*

We have seen in the previous sections various quadrants and portable dials, most of them with markings for the seasonal hours. On each of these instruments it is also possible to represent a curve for the *ʿaṣr* prayer, although Najm al-Dīn did not always explicitly mentioned or illustrated this possibility. In this section we shall consider various instruments specially designed for determining the time of the *ʿaṣr*, and we shall also explore the various ways of representing *ʿaṣr* curves on sine quadrants.

3.5.1 *A simple disk with gnomon for finding the* ʿaṣr

A simple and efficient instrument for finding the time of the *ʿaṣr* is presented in Ch. 89; it is called the "arc of the *ʿaṣr* which is a complete circle". This circle is in fact extrapolated from the usual curve for the *ʿaṣr* on a standard horizontal sundial (*basīṭa*), which can be very well approximated as a circular arc (see Fig. 3.41). Although Najm al-Dīn's instructions are limited to explaining the construction of that circle with respect to a first 'invisible' auxiliary circle centred at the gnomon, its physical realisation and use are not difficult to imagine. The instrument is a flat disk (of some material like wood) with eccentric gnomon (see Fig. 3.40); on this plate the cardinal directions

are marked, and the plate should be aligned properly with them. When in the afternoon the shadow of the gnomon falls exactly on the circumference of this circle, the time for the *ʿaṣr* prayer begins.

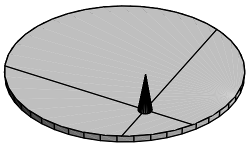


FIG. 3.40. Circle for finding the *ʿaṣr*

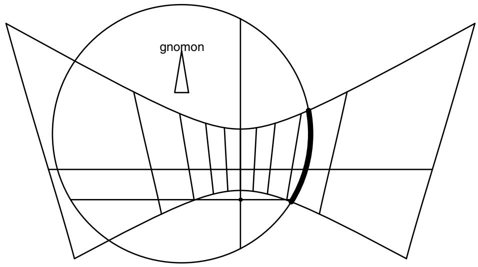


FIG. 3.41. Representation thereof over a horizontal sundial

3.5.2 *Representing the* ʿaṣr *in tropical latitudes*

Najm al-Dīn devotes Ch. 101 to the particular case of representing the *ʿaṣr* on astrolabic plates and sundials for latitudes smaller than the obliquity. In such latitudes, the sun reaches the zenith at midday for a certain value of the declination $\delta_z = \phi$ (since $h_m(\delta_z) = 90° - \phi + \delta_z = 90°$). The solar longitude corresponding to δ_z is called "zenithal degree" (*darajat al-musāmata*). The meridian altitude will then be decreasing in the interval $\delta_z \leq \delta \leq \varepsilon$. This leads to an irregularity in the function $h_a(\lambda)$; Figure 3.42 illustrates this situation for latitude 21° (a value commonly used in the medieval period for the latitude of Mecca). Several medieval astronomers did not realise this irregularity and drew *ʿaṣr* curves on astrolabic plates or sundials for tropical latitudes as circular arcs joining three construction marks. Such is the case with some astrolabes from al-Andalus, which frequently include a plate for latitude 0° or 21°.[114] Najm al-Dīn tells his reader to erase such erroneous *ʿaṣr* curves on astrolabic plates and to engrave them anew. He also adds having heard from an eminent colleague that the treatise by al-Marrākushī contains a drawing of an *ʿaṣr* curve for a latitude of 0° that is represented as a circular arc with a single concavity towards the east. Najm al-Dīn expresses his doubts about whether this should be imputed to the author, and suspects that a copyist might be responsible for this error. Consultation of al-Marrākushī's treatise reveals that a horizontal sundial for latitude 0° is indeed illustrated with an erroneous *ʿaṣr*

[114] An astrolabe by Muḥammad ibn al-Ṣaffār, dated 420 H [= 1029/30], preserved in Berlin, includes several plates for latitudes smaller than the obliquity, all of which display erroneous *ʿaṣr* curves. This astrolabe was described in Woepcke 1858 (without illustrations of the plates in question or mention of the particular shapes of the *ʿaṣr* curves).

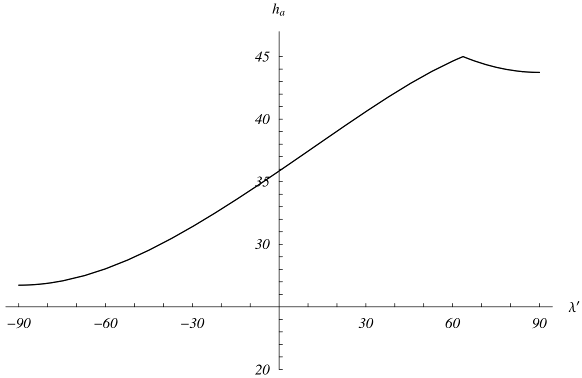


FIG. 3.42. Plot of $h_a(\lambda')$ for $\phi = 21°$

curve exactly as reported by Najm al-Dīn. This mistake not only occurs on the illustration, but is in fact explicit in al-Marrākushī's textual instructions on how to construct the *ʿaṣr* curve.[115] It is thus imputable to the author himself, contrary to Najm al-Dīn's respectful opinion for his eminent predecessor. al-Marrākushī's error – exactly as on the astrolabic plates mentioned above – stems from his computing only three points of the curve at the solstices and equinox and joining them by a circular arc. Exactly the same error was made by none other than Ibn al-Shāṭir on the sundial for latitude 0° engraved on his 'compendium box' called the *ṣandūq al-yawāqīt* which he made in the year 767 H [= 1365/6 AD].[116] On Fig. 3.43 the erroneous arc is shown dashed, next to the accurate curve.

Najm al-Dīn's solution to this problem simply consists in computing additional points of the *ʿaṣr* curve in order to trace two circular arcs from two triplets of points. Five points are needed to make these two triplets: the first segment covers the interval $-\varepsilon \leq \delta \leq \phi$ and the second one $\phi \leq \delta \leq \varepsilon$, so the five points should be computed for these limiting values and for intermediate declinations within each interval. This is not exactly what Najm al-Dīn suggests doing. Although his instructions are partly confused (even after making

[115] al-Marrākushī, *Jāmiʿ*, I, p. 267:1-10 and figure; Sédillot, *Traité*, p. 486 and Fig. 85. The same error is repeated with vertical sundials for latitude zero: see e.g. al-Marrākushī, *Jāmiʿ*, I, pp. 275–277 (figure on p. 277); Sédillot, *Traité*, pp. 499–501 and Fig. 91.

[116] Illustrated in Reich & Wiet 1939-40, p. 201, and King & Janin, plate 3 (with discussion on pp. 201–202, where Ibn al-Shāṭir's error is missed). The *ʿaṣr* curve as such is not visible on the published illustration, but its shape is indicated by the position and curvature of its corresponding kufic inscription *ʿaṣr āfāqī*; in fact the curve might not have necessarily figured on the original instrument, as it could simply have been defined as the upper side of that inscription. The sliding plate on which the sundial is engraved has been lost since 1938, when it was described by S. Reich and G. Wiet.

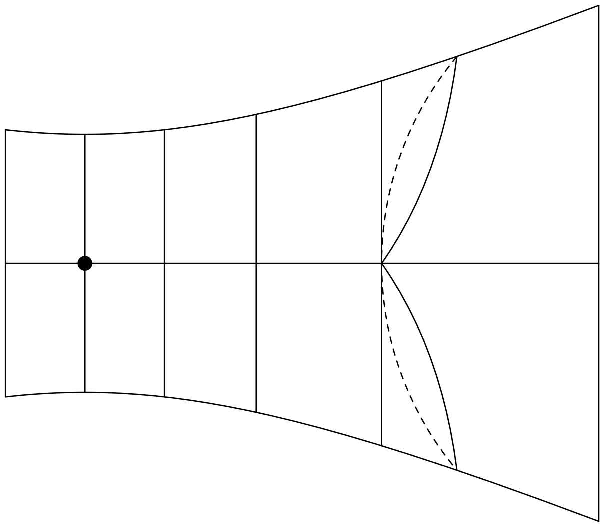


FIG. 3.43. *ʿAṣr* curve on a horizontal sundial for latitude 0°
(al-Marrākushī's erroneous curve is dashed).

some necessary emendations to the manuscript), we can see that he computes the azimuth and shadow length at the *ʿaṣr* for the following declinations $-\varepsilon$, $-\phi$, 0, ϕ and ε, as if he assumed that the singularity occurs at the equinox, whilst in fact it does at $\delta = \phi$, as we have seen. Obviously, this set of points will not provide optimal results. But let us examine the tables which Najm al-Dīn compiled in order to trace irregular *ʿaṣr* curves. Ch. 101 indeed contains two tables of the quantities $\mathrm{Cot}\, h_a(\phi,\delta)$ and $a(h_a,\phi,\delta)$, the first one for $\phi = 0°$ and the second one for $\phi = 12°$. These provide the polar coordinates of selected points of the *ʿaṣr* curve on the sundial. The table for latitude zero is computed for the following declinations: ε, $\delta(45°)$, 0, $-\delta(45°)$ and $-\varepsilon$. This yields, contrary to the procedure advocated in the text, five points which allow us to properly construct two circular arcs approximating the *ʿaṣr* curve. The accompanying illustration of this curve is also drawn correctly. The table for $\phi = 12°$, however, agrees with the problematic instructions given in the text, the polar coordinates being computed for declinations: $-\varepsilon$, $-12°$, 0, 12° and ε. The diagram of the corresponding curve is not successful at all: one arc is drawn with concavity towards the east in the interval $\varepsilon \leq \delta \leq -12°$, and the second one is a straight line from there to the day-line of Capricorn. This is surprising, since the first four entries of the table cannot be joined as a circular arc, even approximatively, and the diagram, if it indeed corresponds to the author's original drawing, leaves the impression that the coordinate for

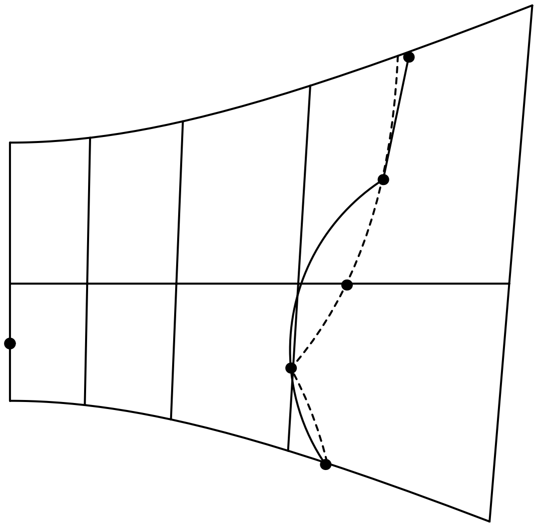


FIG. 3.44. Najm al-Dīn's unsuccessful ʿaṣr curve for latitude 12° (the accurate one is dashed)

$\delta = 0$ has not been taken into consideration. In Fig. 3.44, the entries of the table are represented on the eastern half of a sundial for latitude 12°, and the diagram of the curve in manuscript **D** is shown as a continuous circular arc joined to a linear segment; the accurate curve is shown for comparison with dashes.

3.5.3 *Two "locust's legs" with non-standard gnomons*

We shall examine here two unusual "locust's legs" specifically designed for finding the *ʿaṣr*, presented in Chs. 87 and 92. Taken alone, the instructions on how to construct these dials are so obscure that a proper understanding of their underlying principle is not possible. But a consideration of both the text and the illustrations allows us to reconstruct both instruments with confidence. In the text of both chapters it is clearly referred to a gnomon of variable length, casting a vertical shadow on the appropriate day-line when the dial is oriented toward the sun. The only possible interpretation is that the gnomon is a right triangle, as shown on Fig. 3.45.

Let rectangle *ABCD* be the surface of the dial, and let *BG* be a perpendicular to this surface, with $\widehat{BG} = \widehat{AB}$; then the gnomon will be the diagonal *AG*. For any day-line *EF*, a perpendicular at *E* will meet the gnomon at *H*, and *EH* will represent its actual 'gnomon', since the shadow will be cast on

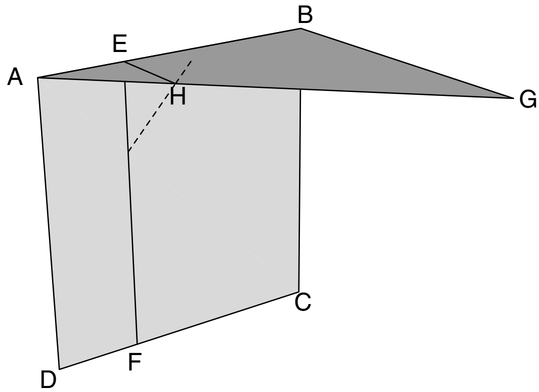


FIG. 3.45. Principle of the universal ʿaṣr dials

day-line EF from point H when the dial is oriented towards the sun, and the height of point H above the dial will be given by $\widehat{EH} = \widehat{AE}$. In Ch. 87, the meridian altitude scale runs from A to B, and in Ch. 92 it runs from B to A. Hence we have an *actual* gnomon length proportional to the meridian altitude in the first case, and proportional to its complement in the second case. The Cartesian coordinates of the ʿaṣr curve (A being the origin, AB the positive x-axis and AD the positive y-axis, assuming $\widehat{AB} = 90$) will be given by:

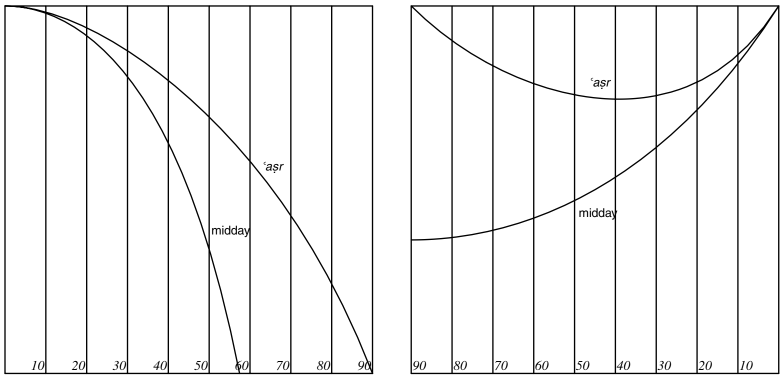
$$x = h_m \quad \text{and} \quad y = h_m \tan h_a = \frac{h_m}{1 + \cot h_m} \qquad \text{(in Ch. 87)}$$

$$x = 90 - h_m \quad \text{and} \quad y = (90 - h_m) \tan h_a = \frac{90 - h_m}{1 + \cot h_m} \qquad \text{(in Ch. 92)}.$$

On both instruments the midday curve is also represented. With a vertical coordinate of $y = h_m \tan h_m$ in the first case, it is clear that it can only be represented up to a certain value of h_m, which depends of the length of the dial (see Fig. 3.46a – note that the midday curve is omitted on the illustration in the manuscript). On the second dial, however, the function $(90 - h_m) \tan h_m$ does converge to a value smaller than 90, namely

$$\lim_{h_m \to 90} (90 - h_m) \tan h_m = 180/\pi = 57.2958\ldots,$$

so that the whole midday curve can be represented on the dial (see Fig. 3.46b). My reconstructions of these curves based on the above formulæ agree well with those in the manuscript.



(a) Version of Ch. 87 (b) Version of Ch. 92

FIG. 3.46. Najm al-Dīn's "locust's legs" with diametral gnomon

3.5.4 ʿAṣr *curves on sine quadrants*

A particularly interesting case of 'nomographic combinatorics' is presented in Ch. 77, in which five different ways of representing the altitude at the *ʿaṣr* on a sine quadrant are discussed (see Plate 15). The first kind of marking for the *ʿaṣr* is based on a simple geometrical procedure that is directly inspired by the geometric definition of the *ʿaṣr* in terms of shadow increase. On quadrant OAB (see Fig. 3.47) with altitude scale AB, a horizontal line CD is drawn at a distance of twelve radial units from the side AO, i.e., $OD = 12$ measures the gnomon length. Najm al-Dīn calls line CD the 'duodecimal shadow scale' (*masāṭir al-ẓill al-ithnā ʿasharī*). When the thread is placed on the meridian altitude at Q, it intersects CD at T, which projects vertically on the radial scale OA at U. Since TU represents the gnomon, OU will measure the shadow length at midday. Adding twelve units to this distance will yield the *ʿaṣr* shadow OV. Projecting V on CD at P and placing the thread upon P, one can read off the altitude at the *ʿaṣr* at S on the altitude scale. This 'duodecimal shadow scale' is frequently found on Ottoman sine quadrants. Najm al-Dīn tells us that it was well known (*mashhūr*) in his days, which explains his laconism. As far as I know, this is nevertheless the first appearance in textual sources. But Najm al-Dīn's indication that it was well-known is confirmed by its being featured on a sine quadrant made by his Damascene colleague al-Mizzī in 730 H [= 1329/30] and now preserved in the Davids Collection, Copenhagen.[117] On this particular quadrant two such lines are found, one horizontal and the other vertical.

[117] The quadrant is described in King 1993b, p. 438, with illustration of the astrolabic side only.

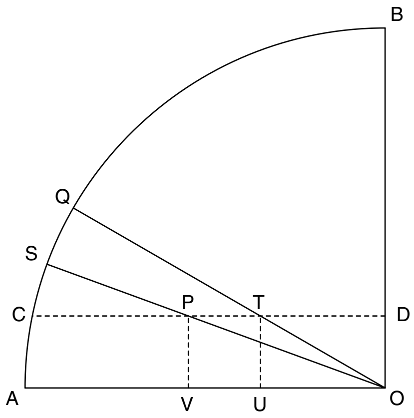


FIG. 3.47. Principle of the 'duodecimal line' for finding the *ʿaṣr*

The four other methods necessitate a numerical table of $h_a(h_m)$, in order to represent this function graphically on the sine quadrant. Najm al-Dīn informs us that whereas there are numerous possible ways of representing the arc of the *ʿaṣr*, those few he chose to describe are sufficient. Before examining these in details, let us consider the problem in its generality. The purpose of marking an *ʿaṣr* curve on a sine quadrant is, of course, to make possible to find graphically the quantity h_a by feeding in the argument h_m. On a sine quadrant, any angular quantity can be input or output in five different ways: as an angle or as a radius, the latter measuring either the Sine or the Cosine of the argument, or even as a rectangular (Cartesian) coordinate. These five coordinates depending upon some argument α are:

$$\rho = \operatorname{Sin}\alpha, \quad \rho = \operatorname{Cos}\alpha, \quad \theta = \alpha, \quad x = \operatorname{Cos}\alpha, \quad y = \operatorname{Sin}\alpha\,.$$

A combination of two of these coordinate expressions for arguments h_m and h_a, will yield a possible coordinate system for the graphical representation of the function $h_a(h_m)$ (and this is obviously true for any function of a single parameter). This makes up a total number of *theoretical* combinations of 18. Eliminating those pairs of coordinates which are meaningless[118] reduces to 9 combinations that effectively correspond to a graphical representation of the *ʿaṣr* altitude on the surface of a quadrant. Since Najm al-Dīn's sine quadrant

The front and back are illustrated in the sale catalogue of Sotheby's, London, 13 April 1988, p. 122, lot no. 267. I have also consulted photographs kept in the Institut für Geschichte der Naturwissenschaften, Frankfurt am Main.

[118] The reader will easily see that it is not possible, for example, to have $y = \operatorname{Sin} h_m$ and $\theta = h_a$, or to have $\rho = \operatorname{Cos} h_m$ and $x = \operatorname{Cos} h_a$.

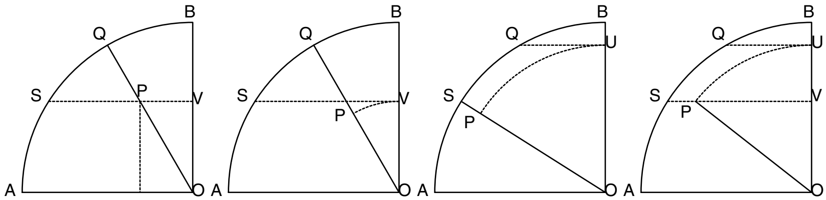


FIG. 3.48. Geometrical construction of four *ʿaṣr* curves on a sine quadrant

in Ch. 77 only displays markings for the sines, and not the cosines, he limited his discussion to those four possibilities that do *not* involve cosines:

$$\mathbf{1}\begin{cases}\theta = h_m\\ y = \operatorname{Sin} h_a\end{cases}\quad \mathbf{2}\begin{cases}\theta = h_m\\ \rho = \operatorname{Sin} h_a\end{cases}\quad \mathbf{3}\begin{cases}\rho = \operatorname{Sin} h_m\\ \theta = h_a\end{cases}\quad \mathbf{4}\begin{cases}\rho = \operatorname{Sin} h_m\\ y = \operatorname{Sin} h_a\,.\end{cases}$$

The following five remaining combinations would require the inclusion of cosine markings (i.e., vertical lines) on the sine quadrant:

$$\mathbf{5}\begin{cases}\theta = h_m\\ \rho = \operatorname{Cos} h_a\end{cases}\quad \mathbf{6}\begin{cases}y = \operatorname{Cos} h_m\\ \theta = h_a\end{cases}\quad \mathbf{7}\begin{cases}x = \operatorname{Cos} h_m\\ y = \operatorname{Sin} h_a\end{cases}$$

$$\mathbf{8}\begin{cases}x = \operatorname{Cos} h_m\\ \rho = \operatorname{Cos} h_a\end{cases}\quad \mathbf{9}\begin{cases}\rho = \operatorname{Cos} h_m\\ \theta = h_a\,.\end{cases}$$

Given the conditions (implicitly) assumed for the problem of representing the *ʿaṣr* on a sine quadrant, Najm al-Dīn indeed exhaustively covered all possibilities. His construction of the *ʿaṣr* curves **1**–**4**[119] is easily explained with reference to the four diagrams in Fig. 3.48, on which the meridian altitude h_m is constantly represented by arc AQ, and the altitude at the *ʿaṣr* h_a by arc AS; the segments OU and OV represent $\operatorname{Sin} h_m$ and $\operatorname{Sin} h_a$. The coordinate system underlying those simple geometrical constructions yield a point P on the curve of the *ʿaṣr*, which is represented in Fig. 3.49. Fo the sake of completion I have represented in Fig. 3.50 the *ʿaṣr* curves resulting from coordinate systems **5**–**9**.

[119] I have numbered the curves in Fig. 3.49 in correspondence with the set of equations given above. The numbering of the *ʿaṣr* curves within Ch. 77 begins with the duodecimal shadow line as ‘number 1’.

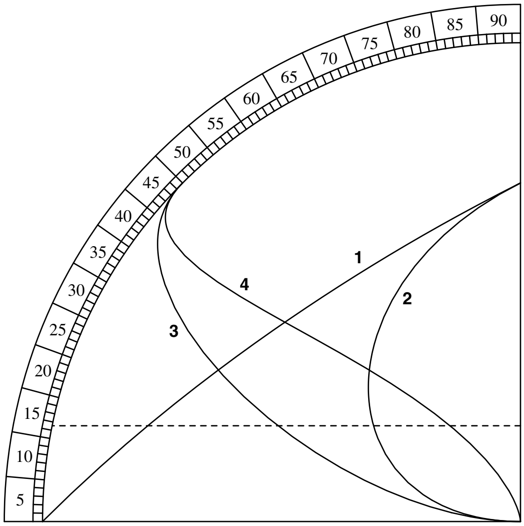


FIG. 3.49. Najm al-Dīn's *ʿaṣr* curves on a sine quadrant

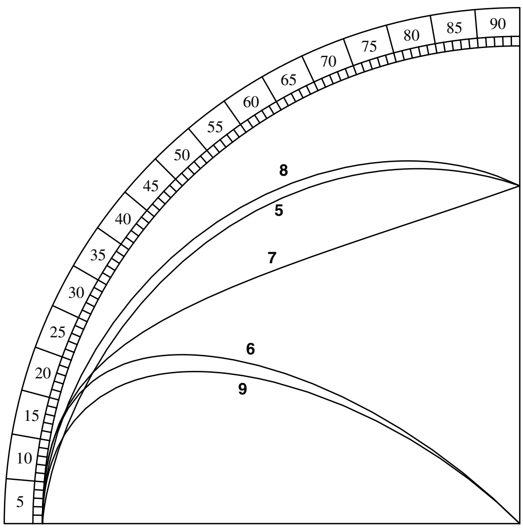


FIG. 3.50. Further possibilities of representing the *ʿaṣr* on a sine quadrant

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CHAPTER FOUR

FIXED SUNDIALS

4.1 *Historical introduction*

A historical survey of gnomonics and of the practice of dialling in Islam still needs to be written.[1] Fixed sundials, unlike any other variety of astronomical instruments, are *public* scientific objects, which are of some concern to a relatively large group of people. Contrary to astrolabes, quadrants or even portable dials, their use does not require any technical knowledge beyond a minimal level of 'literacy'. In Islamic civilization, sundials are intimately associated with a religious context, which can partially be explained by the fact that the times of day prayers were traditionally defined in terms of shadow increases.[2] Archaeological findings inform us that sundials were indeed standard features of medieval religious architecture.[3] Technical treatises on gnomonics from the Mamluk and Ottoman periods are largely authored by *muwaqqit*s or other specialists working in a religious context.

The earliest extant Islamic treatise on sundials is by al-Khwārizmī,[4] who included elaborate numerical tables for constructing horizontal sundials for various latitudes. al-Kindī (*fl. ca.* 850) also composed short treatises on sundials that are of great interest, because they feature graphical methods probably of Indian or Hellenistic origin.[5] Ibn al-Nadīm's *Fihrist* lists numerous treat-

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[1] The only available studies are Schoy 1923 (outdated and with some errors) and King 1996b, pp. 157–170 (brief survey).

[2] King, *SATMI*, II and IV.

[3] For examples of sundials in mosques and madrasas, see e.g. Janin & King 1978, King & Walls 1979; Janin 1972.

[4] *ʿAmal al-sāʿāt fī basīṭ al-rukhāma*, extant in MS Istanbul Aya Sofya 4830, ff. 198v–200r, where it is attributed to al-Khwārizmī. A Russian translation is available: Rozenfeld 1983, pp. 221–234. David King (1999, p. 350) has questioned this attribution, suggesting that Ḥabash would be a more likely candidate, "because Ibn al-Nadīm mentions a treatise on sundial construction by Ḥabash and none by al-Khwārizmī. . . " and because "the most elaborate tables in the set are for latitude 34°, serving Samarra", where Ḥabash is known to have been active. Against this one could reply that 1) Ibn al-Nadīm (*Fihrist*, p. 333) *does* credit al-Khwārizmī with a work on sundials entitled *Kitāb al-Rukhāma*, and 2) other scholars were also active in Samarra, such as the Banū Mūsā and al-Māhānī: see further Charette & Schmidl 2001, pp. 110–111.

[5] Two short texts by al-Kindī are published in Luckey & Hogendijk 1941/1999, pp. 208–219. A more substantial treatise by him entitled *Risāla fī ʿAmal al-sāʿāt fī ṣafīḥatin tunṣabu ʿalā saṭḥin muwāzin li-l-ufuq* is extant in the unique copy MS Oxford Bodleian 663, pp. 190–195, and remains unstudied (a facsimile edition was published in Baghdad by Z. Yūsuf in 1962).

ises on sundials by early Islamic authors that are lost, including al-Fazārī (late eighth century)[6] Ḥabash al-Ḥāsib,[7] al-Farghānī,[8] Muḥammad ibn al-Sabbāḥ,[9] Muḥammad ibn ʿUmar ibn al-Farrukhān,[10] and Abū ʿAbd Allāh al-Shaṭawī.[11] al-Battānī's *Zīj* contains one chapter devoted to the construction of horizontal sundials, with a note on the meridional vertical sundial.[12] The sundial table included in Nallino's edition, found on the last folio of the only extant copy, might not be original to the *Zīj*.[13] There also exists some anonymous works of interest from the early period.[14]

The few available works in the above list are characterised by their *practical* character; they provide graphical and numerical procedures for constructing sundials, usually horizontal ones, without mathematical proofs. A much different impulse to the science of gnomonics was given by Thābit ibn Qurra (210–288 H [= 826–901]), who composed one of the finest treatises on sundial theory in Arabic language. Fortunately his treatise has been published and analysed in the 1930s by Karl Garbers and Paul Luckey, and again more recently by Régis Morelon.[15] For all possible planes (vertical, declining and inclined), Thābit gives (without proof) the horizontal (altitude and azimuth) and Cartesian coordinates of the shadow on this plane, by operating successive coordinate transformations between each plane. Thābit's grandson Ibrāhīm ibn Sinān also composed a work on gnomonics, which is also of interest, especially because of the (aborted) attempt to prove that seasonal hour-lines are not straight,[16] a topic which also motivated the important theoretical contributions of Abū Naṣr Manṣūr ibn ʿAlī ibn ʿIrāq (*fl. ca.* 1000 AD in Khwārizm) and al-Ṣaghānī (late tenth century), who produced the earliest proofs concern-

[6] *Kitāb al-Miqyās li-l-zawāl*, "On meridian gnomons" (Ibn al-Nadīm, *Fihrist*, p. 332; cf. Sezgin, *GAS*, VI, p. 124).

[7] Two works: *Kitāb al-Rakhāʾim wa-l-maqāyis*, "On plane sundials and gnomons" and *Kitāb ʿAmal al-sutūḥ al-mabsūṭa wa-l-qāʾima wa-l-māʾila wa-l-munḥarifa*, "Construction of (sundials on) horizontal, vertical, inclined and declining surfaces" (Ibn al-Nadīm, *Fihrist*, p. 334; cf. Sezgin, *GAS*, V, p. 276).

[8] *Kitāb ʿAmal al-rukhāmāt*, "Construction of plane sundials" (Ibn al-Nadīm, *Fihrist*, p. 337; cf. Sezgin, *GAS*, VI, p. 151).

[9] *Risāla fī Ṣanʿat al-rukhāmāt*, "On the construction of plane sundials" (Ibn al-Nadīm, *Fihrist*, p. 335; cf. Sezgin, *GAS*, V, p. 253).

[10] *Kitāb al-Miqyās*, "On the gnomon" (Ibn al-Nadīm, *Fihrist*, p. 332; cf. Sezgin, *GAS*, VI, p. 137).

[11] Two works: *Kitāb ʿAmal al-rukhāma al-munḥarifa*, "Construction of the declining sundial" and *Kitāb ʿAmal al-rukhāma al-muṭabbala*, "Construction of the drum-shaped sundial" (Ibn al-Nadīm, *Fihrist*, p. 339; cf. Sezgin, *GAS*, VI, p. 205).

[12] al-Battānī, *Zīj*, III, pp. 203–208 (text); I, pp. 135–138 (translation). Cf. Schoy 1923.

[13] al-Battānī, *Zīj*, II, pp. 188, 296.

[14] See for example the short text in MS Aya Sofya 4830, f. 193r, referred to on p. 205 below.

[15] See Garbers 1936; Luckey 1937-38; Morelon 1984, pp. 131–164. Another, shorter treatise by Thābit on the conical sections defined on a horizontal sundial is also included in Morelon's edition of his *œuvres* on pp. 118–129.

[16] Published in Luckey & Hogendijk 1941/1999.

ing the nature of these lines.[17] An important theoretical treatise devoted by Ibn al-Haytham to this very question – presenting a valid demonstration – is extant and awaits study.[18] Ibn al-Ādamī (or al-Samarqandī[19]) wrote a lengthy treatise on the construction of declining vertical sundials, which includes several auxiliary tables serving to compute the Cartesian coordinates of various points on the hour-lines.[20]

From al-Andalus only one treatise of any consequence is known on the topic; it was written by Ibn al-Raqqām, a well-known astronomer, who also reveals himself as an able gnomonist; his constructions are based on analemma constructions. The treatise is available in an edition with translation and commentary.[21] The Maghribi émigré in Cairo al-Marrākushī presented in his *Jāmiʿ* the most comprehensive treatment of gnomonics ever written before the Renaissance.[22] Some sections were analysed by Delambre in his *Histoire de l'astronomie du moyen-âge* in his usual condescending style.[23] A century later Karl Schoy analysed other sections with more enthusiasm and a sound historical judgment.[24] Yet, as with the rest of his monumental work, al-Marrākushī's treatment of gnomonics has remained largely and unjustifiably neglected, and still awaits the investigation it deserves. Here I refer only in passing to those sections that are relevant to Najm al-Dīn's presentation.

A contemporary of al-Marrākushī, Shihāb al-Dīn al-Maqṣī, inaugurated the very practical Mamluk tradition of compiling a set of ready-made numerical tables for constructing various sundials for a specific locality, in this case Cairo.[25] A recension of this work was written by the Damascene *muwaqqit* Ibn al-Majdī (*fl.* second half of the fifteenth century), who added tables for Damascus.[26] Ibn al-Majdī also wrote an important and influential work on

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[17] See Hogendijk 2001.

[18] See Hogendijk's remarks in Luckey & Hogendijk 1941/1999, p. x, n. 10. Ibn al-Haytham also wrote a treatise of a less theoretical nature on horizontal sundials: see *ibid.*, pp. 25–26 and Sezgin, GAS, V, p. 368, no. 20.

[19] The copyist of the unique manuscript was unsure of the authorship, but see the next note.

[20] *Takhṭīṭ al-sāʿāt*, MS Paris 2056, ff. 1–37; cf. King 1996a, p. 160–161. The following argument could be advanced in favour of the authorship of Ibn al-Ādamī: Ibn al-Nadīm lists among the books by Ibn al-Ādamī a *Kitāb Inḥirāf al-ḥayṭān wa-ʿamal al-sāʿāt*, which fits perfectly well with the contents of the above treatise.

[21] Carandell 1988.

[22] Material on gnomonics is contained in the first three *fann*s: *faṣl*s 72–82 of *fann* 1 concern trigonometric calculations relevant to gnomonics; *muqaddima*s 34–43 of *fann* 2, *qism* 1, concern graphical constructions (including analemmas); and *fann* 2, *qism* 3, in 42 *faṣl*s, concern the construction of fixed sundials. See al-Marrākushī, *Jāmiʿ*, I, pp. 162:18–175:1, 211:12–225:17, 258:17–357:14; Sédillot, *Traité*, pp. 326–342, 404–422, 475–619.

[23] Delambre 1819, pp. 523–526, 533–534, 544.

[24] Schoy 1923.

[25] His work entitled *Shifāʾ al-asqām fī waḍʿ al-sāʿāt ʿalā al-rukhām* exists in several manuscripts; see the brief remarks in King 1996b, p. 163.

[26] MS Vatican Borg. 105, ff. 18r–19r.

sundial theory;[27] in a different work he informs us that Ibn al-Sarrāj had also composed a treatise on the topic, alas lost.[28] Other late Mamluk authors on the topic include al-Muhallabī, al-Karādīsī, Sibṭ al-Māridīnī, and Ibn Abi ’l-Fatḥ al-Ṣūfī.[29]

4.2 *Theoretical introduction*

The following is intended as a supplement to Olaf Pedersen’s article “A Few Notes on Sundials”,[30] with special considerations for medieval Islamic gnomonics. The purpose is to provide the modern reader with the mathematical formulæ and concepts which facilitate the understanding of the procedures presented by medieval authors.

Assume a Cartesian coordinate system with the x–axis towards the south, the y–axis towards the east and the z–axis towards the zenith. If the surface of the sundial is a plane of declination D (deviation of the vector normal to the plane with respect to the meridian) and inclination I (deviation of the normal vector with respect to the zenith), then the plane of the sundial will be defined by the equation

$$x\cos D\,\sin I + y\sin D\,\sin I + z\cos I = 0\,. \tag{4.1}$$

Furthermore, assume a gnomon of length unity perpendicular to the plane. If O represents the base of this gnomon and G its extremity, then

$$\vec{OG} = (\cos D\,\sin I, \sin D\,\sin I, \cos I)\,.$$

If $\vec{e}$ is a unitary vector giving the direction of the shadow cast at G and if P gives the coordinates of the shadow intercepted on the plane of the sundial

$$\vec{OP} = (x,y,z) = \vec{OG} + \lambda\,\vec{e}\,,$$

which can be written as

$$\begin{aligned} x &= \cos D\,\sin I + \lambda\ e_x \\ y &= \sin D\,\sin I + \lambda\ e_y \\ z &= \cos I + \lambda\ e_z\,. \end{aligned} \tag{4.2}$$

Solving the systems of equations (4.1) and (4.2) for the parameter λ yields:

$$\lambda = -\frac{\cos^2 I + \cos^2 D\,\sin^2 I + \sin^2 D\,\sin^2 I}{\cos D\,\sin I\ e_x + \sin D\,\sin I\ e_y + \cos I\ e_z}\,.$$

[27] See King, *Survey*, p. 73.
[28] This treatise was entitled *al-Miftāḥ*: see MS Damascus Ẓāhiriyya 4133, f. 101r.
[29] See King, *Survey*, nos. C67, C90, C97 and C98.
[30] Pedersen 1987.

Before substituting this result in (4.2), introduce a coordinate transformation by rotation $(x,y,z) \rightarrow (\xi,\eta,\zeta)$ in order to have the η-axis correspond to the line of steepest descent on the sundial plane, the ξ-axis to the line parallel to the horizon and the ζ-axis perpendicular to the plane. This is achieved by applying to the vector $\vec{OP}$ the rotation matrix $\mathscr{A}$ defined by the Euler angles $\varphi = \frac{\pi}{2} + D$, $\theta = I$ and $\psi = 0$:[31]

$$\mathscr{A} = \begin{pmatrix} -\sin D & \cos D & 0 \\ \cos D \cos I & \cos I \sin D & \sin I \\ \cos D \sin I & \sin D \sin I & \cos I \end{pmatrix}$$

The equation $(\xi,\eta,\zeta) = \mathscr{A} \cdot \vec{OP}$ will then yield:

$$\begin{aligned} \xi &= -\lambda \sin D\, e_x + \lambda \cos D\, e_y \\ \eta &= -\lambda\, (\cos D \cos I\, e_x + \cos I \sin D\, e_y - \sin I\, e_z) \\ \zeta &= 1 + \lambda \cos D \sin I\, e_x + \lambda \sin D \sin I\, e_y + \lambda \cos I\, e_z\,. \end{aligned} \tag{4.3}$$

which becomes, after substitution of λ:[32]

$$\begin{aligned} \xi &= \frac{\sin D\, e_x - \cos D\, e_y}{\cos D \sin I\, e_x + \sin D \sin I\, e_y + \cos I\, e_z} \\ \eta &= \frac{\cos D \cos I\, e_x + \cos I \sin D\, e_y - \sin I\, e_z}{\cos D \sin I\, e_x + \sin D \sin I\, e_y + \cos I\, e_z} \\ \zeta &= 0\,. \end{aligned} \tag{4.4}$$

Now, if A represents the solar azimuth measured from the positive x-axis (i.e., anticlockwise from the south[33]) and h the solar altitude, the coordinates of $\vec{e}$ follow:

$$\begin{aligned} e_x &= -\cos A \cos h \\ e_y &= -\cos h \sin A \\ e_z &= -\sin h\,. \end{aligned}$$

Substituting these in equation (4.4) we obtain

$$\begin{aligned} \xi &= -\frac{\cos h \sin(A-D)}{\cos I \sin h + \cos(A-D) \cos h \sin I} \\ \eta &= \frac{\cos(A-D) \cos h \cos I - \sin h \sin I}{\cos I \sin h + \cos(A-D) \cos h \sin I}\,. \end{aligned} \tag{4.5}$$

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[31] The second term of the right-hand side of equation 14b in Pedersen 1987 should read $-y \cos I \sin D$ instead of $-y \sin I \sin D$.

[32] Pedersen (1981, p. 300) substitutes λ in the equation for $\vec{OP}$ *before* applying the rotation matrix; our method leads to simpler analytical expressions (but is not necessarily superior from a purely analytical point of view).

[33] Note that in Islamic astronomy the azimuth a is usually measured from the east, so that $a = 90° - A$.

When $I = 90^\circ$, the special case of a vertical sundial,

$$\begin{aligned} \xi_v &= -\tan(A-D) \\ \eta_v &= -\sec(A-D)\tan h\,. \end{aligned} \tag{4.6}$$

Equation 4.5 can be expressed in terms of ξ_v and η_v:

$$\begin{aligned} \xi &= \frac{\xi_v}{\sin I - \cos I\,\eta_v} \\ \eta &= \frac{\cos I + \sin I\,\eta_v}{\sin I - \cos I\,\eta_v} = \frac{\cot I + \eta_v}{1 - \cot I\,\eta_v}\,. \end{aligned} \tag{4.7}$$

The coordinates in terms of the equatorial parameters t, δ are given in Pedersen 1987, where the analytical equations of the hour and declination curves are derived.

Muslim authors on sundial theory frequently considered inclined sundials with a gnomon parallel to the horizon. On a surface of inclination I consider a perpendicular gnomon with length g and a horizontal one with length g'. If the tip of both gnomons coincide then $g = g'\sin I$. Moreover the distance between the bases of both gnomons will be given by $g'\cos I$. The coordinates (ξ', η') measured from the base of the horizontal gnomon will be given in terms of ξ and η (representing the coordinates measured from the base of a perpendicular gnomon of unitary length):

$$\xi' = g\,\xi = g'\sin I\,\xi = -g'\frac{\sin(A-D)\cos h}{\cos(A-D)\cos h + \sin h\cot I}$$

$$\begin{aligned} \eta' = g\,\eta - g'\cos I &= g'\left(\frac{\cos(A-D)\cos h\cos I\sin I - \sin h\sin^2 i}{\cos(A-D)\cos h\sin I + \sin h\cos I} - \cos I\right) \\ &= -g'\frac{\sin h}{\cos(A-D)\cos h\sin I + \sin h\cos I}\,. \end{aligned}$$

ξ' and η' can again be expressed in terms of ξ_v and η_v:

$$\begin{aligned} \xi' &= \frac{\xi_v}{1 - \cot I\,\eta_v} \\ \eta' &= \frac{\eta_v}{\sin I - \cos I\,\eta_v}\,. \end{aligned} \tag{4.8}$$

4.3 *Najm al-Dīn's approach to gnomonics*

The generic appellation for sundials in general is *rukhāma*, "marble slab", which refers to the material out of which sundials were usually constructed.[34] All further specific designations are built from that word, keeping only the adjectival part. Thus, a horizontal sundial, which al-Battānī calls *al-rukhāma al-basīṭa* "the flat, horizontal sundial [plate]" or *al-āla al-basīṭa* "the flat instrument",[35] is simply called a *basīṭa* by later authors.[36] In the present treatise, a vertical sundial is called a *qāʾima*, "the (sundial) which stands up vertically". This term is employed in Chs. 107 and 122, where the sundials featured are called [*al-rukhāma*] *al-qāʾima ʿalā khaṭṭ niṣf al-nahār* and *al-qāʾima ʿalā khaṭṭ al-mashriq wa-al-maghrib*. This translates literally as "the (sundial) which stands vertically upon the meridian (or east-west) line", that is, which is parallel to it.

The declination (*inḥirāf*) d of a wall or marble plate, is defined as the angle made between its southernmost extremity and the meridian line (in the theoretical part above we rather defined the declination D as the angle between the normal to the sundial plane and the meridian, which is the complement of Najm al-Dīn's *inḥirāf*). When the southernmost extremity of the wall or plate is in the eastern quadrant, the sundial is declining towards the east, and likewise when it is in the western quadrant (which is again the opposite of the modern definition). The Arabic term designating a declining sundial is built with the active participle of the verb *inḥarafa* ('to decline'): *munḥarifa*.

On vertical or inclined sundials the vertical axis is called *khaṭṭ al-watad*, "pivot line", and the gnomonic projection of the horizon is called *khaṭṭ al-ufq*, "horizon line". The inclination (*mayl*) of the sundial is defined as the angle made between the line of steepest descent on its surface and a vertical line. In Ch. 102 a horizontal sundial is thus defined as a sundial of inclination 90°. It is further necessary to specify the direction towards which the surface is inclined and the side on which the sundials is made. For example, for a sundial of declination 90°, Najm al-Dīn will indicate whether it is inclined towards the east or towards the west, and whether its markings are on the side which faces the sky or on that which faces the ground.

4.3.1 *Description of Najm al-Dīn's sundial tables*

In the sole manuscript source of Najm al-Dīn's table for constructing sundials (**D**:47r), the azimuth, oddly enough, is lacking. It is difficult to assume that

[34] This word is attested in the context of gnomonics already in the early-ninth century in a treatise by al-Khwārizmī, on which see p. 181, n. 4 above.

[35] See al-Battānī, *Zīj*, III, pp. 203–208.

[36] The earliest occurrence seems to be in Ibn Yūnus' *Zīj*: see Schoy 1923, p. 27. This is also the term used by al-Marrākushī and standard thereafter.

the azimuth was already missing in his original table, since in his introduction (**D**:26v–27r; cf. translation p. 233) Najm al-Dīn informs us that he has compiled a sundial table in which "the shadow for each hour and its azimuth (are tabulated for) each sign of both solstices". Presumably there was a third column for the azimuth under the heading 'Cancer' and 'Capricorn', which was omitted by a copyist.

In addition to a table for the seasonal hours, there was a second one for the equal hours. This equal-hour table is not extant in **D**. The third sundial table mentioned in the introduction corresponds exactly to the table found in **D**:95v. Finally, a table giving the horizontal and vertical shadows as functions of the altitude for each 5° or 6° of argument (these are simply the cotangent and tangent functions to base twelve) was also compiled by Najm al-Dīn, but it is not found in **D**.[37]

4.3.2 *Horizontal sundials*

The construction of horizontal sundials presents no difficulty once the necessary numerical tables have been compiled. In Chs. 79–82, Najm al-Dīn gives the procedure for constructing various markings on horizontal sundials with the help of such tables. In the standard case (Ch. 79), the declination curves for each zodiacal sign and the hour-lines for the seasonal hours 1–11 are represented. The text assumes a table in which the horizontal shadow ($\mathrm{Cot}\,h$) and the azimuth (a) are tabulated for each seasonal hour (from 1 to 6) and for both solstices. For the remaining zodiacal signs, only the horizontal shadow is tabulated for the same seasonal hours.

Najm al-Dīn's construction consists in tracing a basic circle with graduated circumference on the ground with the meridian and the east-west lines as diameters. The centre represents the base of the gnomon. A ruler is placed at the centre and on the circular scale upon the opposite of the azimuth at the desired hour and declination. The compass is then opened to the value of the corresponding horizontal shadow and one leg is put at the centre; a mark is made with the other leg at the side of the ruler. Such marks are made for both solstices only, and are then joined to form the solstitial declination curves; the hour-lines are traced as straight lines between them. For the equinoctial line it is only necessary to mark the midday shadow at the equinox on the meridian line, and to trace a straight line perpendicular to the meridian. The remaining declination curves are then traced by opening the compass to the shadow length for this declination at each hour, and by making a mark on the respective hour-lines. The construction of the curve for the *ʿaṣr* is not mentioned in the text, but the procedure is straightforward. Three marks on the solstitial and equinoctial day-lines are constructed by means of the polar coordinates

[37] The tables accompanying Chs. 63 and 64 include entries of $\mathrm{Cot}\,h_m$ and $\mathrm{Tan}\,h_m$, with $h_m = 10°, 20°, \ldots, 90°$, but these are certainly unrelated to the tables referred to here.

(shadow and azimuth) and are joined to form a circular arc. The special case of *ʿaṣr* curves on horizontal sundials for latitudes smaller than the obliquity is treated in Ch. 101 (see Section 3.5.2). The illustration in **D**, which is not in the hand of the main copyist, erroneously shows the *ʿaṣr* curve on the western side.

Ch. 80 introduces a sundial which, in addition to the standard markings presented in Ch. 79, bears circles indicating the altitude of the sun. These are concentric to the gnomon and their radii are given simply by $\mathrm{Cot}\,h$ (cf. the simple instrument of Ch. 83, presented in Section 3.4). In Ch. 81 a procedure for constructing lines of the hour-angle is presented, which is similar to the procedure for drawing seasonal hour-lines. Najm al-Dīn does not give any indication about the outer limits of the sundial, but these appear to be as usual the first and eleventh seasonal hour-lines. For hour-angles larger than the hour-angle corresponding to the first or eleventh hour at winter solstice, the hour-angle lines will intersect these two boundary hour-lines at a certain value of the declination. In such cases, in addition to the mark placed on the declination curve of Cancer, a second mark will be placed on a declination curve chosen so that it occurs within the range of the sundial. The same reasoning applies in Ch. 82, which describes the construction of the equal hours on a sundial whose boundaries are again not specified. Those equal hours are counted either from sunrise or from midday. In the treatise (**D**:48r) the illustration reveals lines of equal hours since sunrise: nine hour-lines intersect the declination curve of Capricorn, and fifteen intersect that of Cancer. The western boundary of the sundial is the first equal hour-line, and the eastern one is the vertical right-hand side of the frame containing the illustration.

A remarkable horizontal sundial featured in Ch. 113

A remarkable horizontal sundial, illustrated on two facing pages in Ch. 113 (**D**:32v–33r – reproduced on Plate 13), includes on one instrument all the markings that are described above (Chs. 79–82). The incomplete illustration bears in addition to seasonal hour-lines a set of declination curves for each 10° of solar longitude (represented only in the intervals between the first and second, and the tenth and eleventh, seasonal hour-lines), lines of the hour-angle for each 5° (numbered along the eleventh hour-line), and altitude circles (not numbered, perhaps for each 6° of altitude?). Along the eleventh hour-line there is a longitude scale with divisions for 10° of each zodiacal sign, and subdivisions for each 2°. The symmetric longitude scale along the first hour-line is left blank. The sundial is bound by a trapezoidal scale on which divisions for the azimuth are inscribed incompletely. Finally, four straight lines with a *ca.* 45° slope towards the centre are traced within each half of the sundial: these seem to be degenerate and incomplete representations of equal hour-lines since sunrise and until sunset. Fig. 4.1 presents a reconstruction of Najm al-Dīn's complex horizontal sundial (displaying the seasonal hours

1–11, lines of hour-angle at each 5°, curves of the beginning and end of the *ʿaṣr*, day-lines for each 10° of longitude, azimuth lines at each 5°, and altitude circles at each 6°).

The text gives no hint about the nature of the markings displayed on the sundial. It simply enumerates all problems of timekeeping which can possibly be solved with it. The first part of the list contains 30 items: **1** solar longitude, **2** declination, **3** meridian altitude, **4** time elapsed (of daylight) in seasonal and **5** equal hours, **6** hour-angle, **7** altitude at the (beginning of the) *ʿaṣr* and **8** at its end, **9** altitude at the seasonal and **10** equal hours, and **11** their azimuth and **12** direction, **13** number of equal hours (during daylight), **14** altitude in the prime vertical, **15** (time) between the *ẓuhr* and the *ʿaṣr*, **16** (time) between the (beginning of the) *ʿaṣr* and sunset, **17** (time) between the beginning and end of the *ʿaṣr*, **18** (time) between the (end of the) *ʿaṣr* and sunset, **19** (time) between the *ẓuhr* and the end of the *ʿaṣr*, **20** durations of the (seasonal) hours, **21** (solar) azimuth at the beginning of the *ʿaṣr* and **22** azimuth at its end, **23** azimuth (corresponding to) any altitude, **24** direction of the sun, **25** time-arc, **26** altitude of the sun in the *qibla*, **27** azimuth of the *qibla* and **28** its direction, **29** time-arc (of the sun when it is in the azimuth) of the *qibla*, **30** hour-angle (of the sun when it is in the azimuth) of the *qibla*. The rest of the list concerns operations which can be performed when supplementary markings are added to the sundial illustrated. These are: **31** half arc of daylight, **32** ortive amplitude, **33** ascension of the ascendant and **34** of the descendant, **35** midday shadow, **36** shadow at the beginning and **37** end of the *ʿaṣr*. The text claims that the total sum of operations is 41, which is somewhat too optimistic.

This sundial is an important testimony of an otherwise unknown tradition of making sundials with complex superpositions of markings, to which belongs the splendid sundial made by Ibn al-Shāṭir for the Umayyad Mosque in Damascus in 773 H [= 1371/2], which has been rightly described as "the most sophisticated sundial of the Middle Ages".[38]

In Ch. 102 an alternative procedure for constructing horizontal sundials is presented, which is of little practical interest but quite interesting from other points of view. It consists in determining the Cartesian coordinates on the horizontal sundial in terms of the Cartesian coordinates on a vertical sundial facing the south, by regarding the horizontal sundial as a sundial with inclination $i = 90°$. It is thus a special case of inclined sundial, discussed at the end of Section 4.3.4 (p. 202).

[38] The sundial is described in Janin 1972. The original archaeological report by A. K. Rihaoui [*Annales Archéologiques de Syrie* 11/12 (1961-62)], of its discovery in 1958 is reprinted in Kennedy & Ghanem 1976, pp. 69–72. The quotation is from King, *SATMI*, VIII.

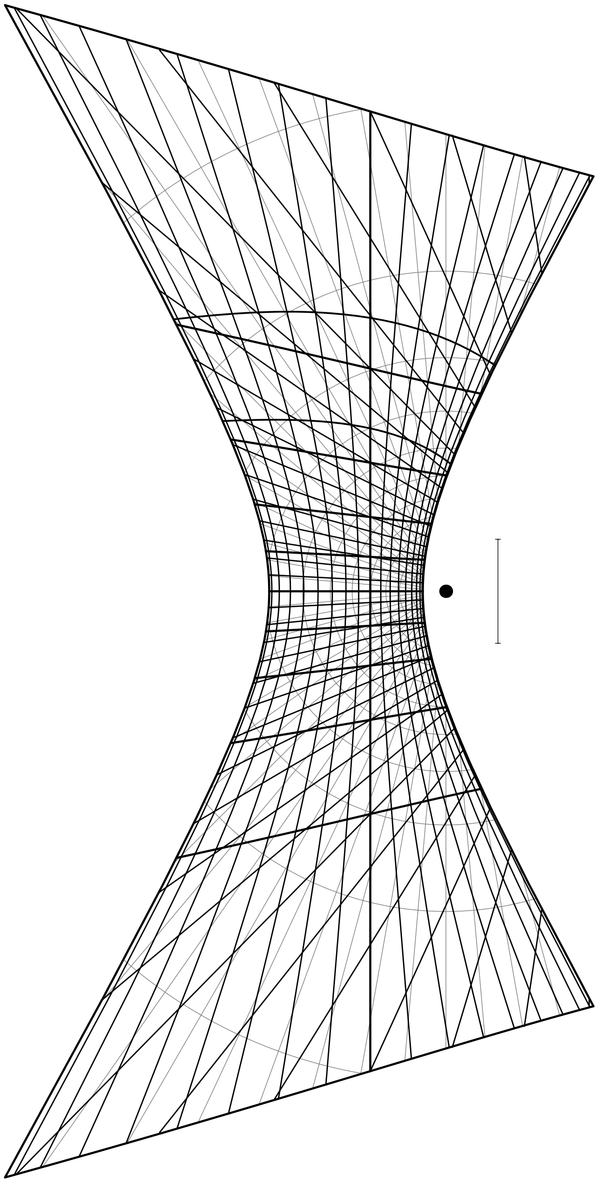

FIG. 4.1. Najm al-Dīn's complex horizontal sundial

4.3.3 *Vertical sundials*

Najm al-Dīn's procedure for constructing vertical sundials combines the use of a single numerical table with simple geometrical constructions. This has the advantage that only one sundial table – the *jadwal al-basīṭa* introduced above – is used for all vertical sundials. The only entries needed are the vertical shadows and azimuths at the seasonal hours, for the solstices and equinox.

In the plane of the meridian

A construction procedure for a vertical sundial in the plane of the meridian is presented in Ch. 107; we summarise it with reference to Figure 4.2. On the vertical surface of the wall (or marble plate – *rukhāma*), line *CD* represents the base of the wall and *E* the position of the gnomon, which is always considered perpendicular to the surface of the sundial. Line *AB* passing through *E* represents the gnomonic projection of the horizon on the sundial, and is hence called the "horizon line" (*khaṭṭ al-ufuq*). The perpendicular *EF* to *AB* at *E* is called the "earth-axis line" (*khaṭṭ watad al-arḍ* or *khaṭṭ al-watad*); it represents the gnomonic projection of the prime vertical. Trace semicircle *AGB* centred at *E* and divide it into 180 equal parts. On line *EF* mark point *I* so that the distance *EI* measures the gnomon length, and trace line *XY* parallel to *AB* passing through *I*. To construct the mark corresponding to the extremity of the shadow when the sun has azimuth a and vertical shadow $\text{Tan}\, h$, count the azimuth a on the graduations of the semicircle, starting from *G*, either towards the right when the azimuth is southerly, or towards the left when it is northerly, and make a mark on the circumference at *H*. Trace radius *EH*, which intersects line *XY* at *J*. Draw *KL* through *J* perpendicular to *AB*. The segment *EK* is called the "distance" (*al-buʿd*), i.e., the horizontal component of the shadow expressed in rectangular (Cartesian) coordinates. Hence point *K* is called "place of the distance of the hour" (*mawḍiʿ buʿd al-sāʿa*), and line *KL* "line of the distance of the hour" (*khaṭṭ buʿd al-sāʿa*). Then a new construction scale has to be made on which the distance $IK = EJ$ will measure 12 parts, which is the gnomon length. The compass is then opened on this scale to the vertical shadow $\text{Tan}\, h$. One leg is put upon *K* and a mark is made at point *M* on line *KL*. Segment *KM* is called the "auxiliary shadow" (*al-ẓill al-mustaʿmal*) and represents the vertical component.[39] Point *M* thus gives the position of the shadow. This procedure is repeated until all marks have been constructed on the surface, which are then joined to form the declination curves of both solstices and the seasonal hour-lines.

Najm al-Dīn does not mention the construction of the equinoctial declination curve, which is a straight line as always. It can be constructed by putting

[39] The same terminology for rectangular coordinates is used by al-Marrākushī.

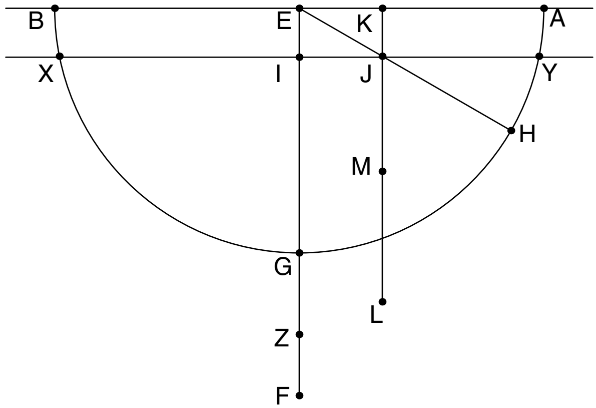

FIG. 4.2. Construction of a vertical sundial in the plane of the meridian

a ruler at the centre *E* and upon the southernmost azimuth of the sundial (this would be the fifth seasonal hour in the case of an eastern sundial) on the graduation of the semicircle. Because this type of sundial cannot intercept the midday shadow, Najm al-Dīn suggests to add markings on the ground to indicate the midday shadow of the gnomon. For this purpose the tip of the gnomon is projected vertically on the ground, and from there a line parallel to the wall is traced in the northern direction to represent the projection of the meridian (see Figure 4.3). The horizontal midday shadows (presumably at each zodiacal sign, but the text is silent about this detail) are marked on this line, whilst assuming a 'gnomon length' that equals EF, which is the height of the gnomon above the ground.

In the plane of the prime vertical

No chapter of Najm al-Dīn's treatise considers the case of a vertical sundial in the plane of the prime vertical with gnomon oriented towards the south. This was perhaps featured in either Ch. 117 or in Ch. 118, which are lacking in the unique copy. It is easy, however, to imagine the procedure for this case, which is almost identical to that given above. The only difference is that the azimuth should be counted on the graduation of semicircle *AGB* from *B* instead of *G*.

In Ch. 122 – which closes manuscript **D** – the case of the northern side of such a sundial is considered. Unfortunately, the page containing the text of this chapter is severely damaged, so that only fragments are legible. Yet it is not difficult to reconstruct the underlying construction procedures on the basis of previous chapters. On this sundial, only the markings corresponding to a northerly solar azimuth can be represented, that is, the declination curves for Gemini and Cancer and the hour-lines 0–2 and 10–12.

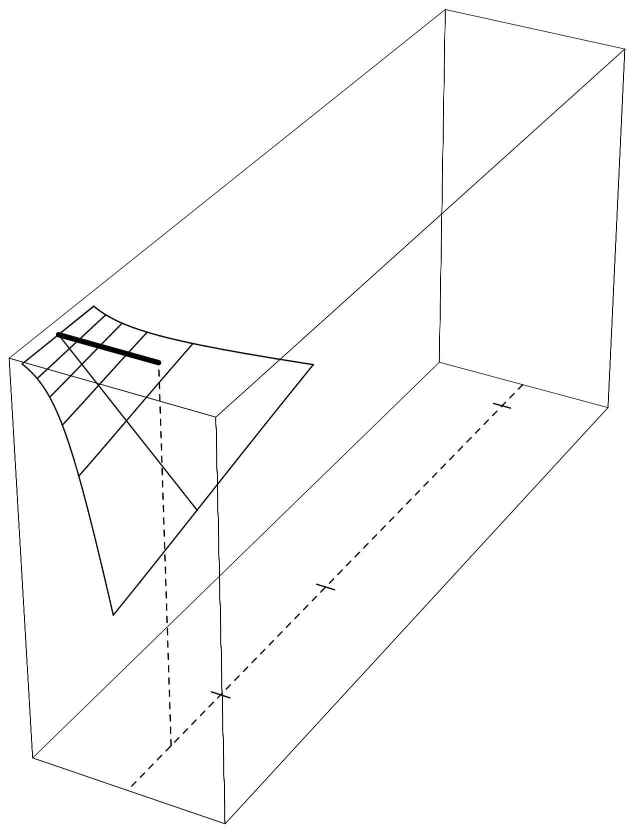

FIG. 4.3. A three-dimensional representation of the sundial in Ch. 107

The beginning of Ch. 122 is incomprehensible, but the legible fragments do not give the impression of being related to the specific problem of a northern vertical sundial. The construction of such a sundial is mentioned from line 8 onward. First it is stated that the construction is only possible for southern declinations of the sun. There follows a numerical procedure for determining the gnomon length, assuming that the given size of the sundial will encompass the desired markings. The reader is asked to consider the smallest northerly azimuth, which Najm al-Dīn gives as the azimuth of the third seasonal hour at summer solstice, with numerical value 0;54° (north) [error: +13]. Take the Cotangent thereof: $\mathrm{Cot}\,0;54^\circ = 763;[50]$.[40] Twice this value will be 1527;40, and twelve parts thereof will correspond to the gnomon length. Thus, 1527;40 is considered as the width of the wall (or sundial plate), from which a gnomon

[40] This is the corresponding entry in Najm al-Dīn's Cotangent table (error: -3).

length is derived which allows us to mark the third seasonal hour at summer solstice on the sundial. But the reader can imagine that with such a ratio (12 : 1527;40) the gnomon would be minuscule and most of the markings would be cluttered around it – unless one really intends to install a sundial on a wall of huge proportions. The rest of the construction in Ch. 122 is identical to the general procedure for declining sundials, to which I now turn.

Declining sundials

The procedure presented in Ch. 109 – similar to that described above – can be used for constructing vertical sundials with any declination with respect to the meridian. A circle (see Fig. 4.4) is traced on the ground in front of the vertical surface of the sundial and tangent to it (at O), with a radius CO corresponding to the gnomon length. The point of contact of the circle at the bottom of the wall should also be underneath the gnomon J. On the surface of the sundial the "horizon" AB is traced as usual. The cardinal directions are then determined and are traced as the diameters of the circle (NS and EW), whose extremities on the side of the sundial are extended until they meet the bottom of the vertical surface (at W' and N'). For a given azimuth, the corresponding "distance" can be constructed on the surface of the sundial by marking this azimuth on the circle, e.g. at M, and by projecting it on line XY through the centre O of the circle at M'. The 'distance' will be given by CM' and line $M'H$ will represent the "line of the distance". To find the "auxiliary shadow" one has to consider OM' as a gnomon, and to compute the vertical shadow at the time sought with this gnomon length. Najm al-Dīn suggests doing this graphically by dividing OM' into 12 parts and by constructing a new scale from these divisions on which the shadow will be taken with the compass. This distance will be transferred as segment HK on line HM', and point K will be the position of the shadow on the sundial. These marks are made for each seasonal hours at both solstices. Then the mark for the sixth hour at the equinox is made on line QN', with QR representing the midday vertical shadow when the gnomon length corresponds to ON'. Line FR will represent the equinoctial line on the sundial. The marks for the intermediate hours at the equinox are easily constructed as the intersections of the 'distance lines' corresponding to their azimuths with the equinox line. The solstitial curves and the hour-lines are then traced by connecting their respective marks.

Najm al-Dīn's illustrations of vertical declining sundials

The following is a description of the declining sundials illustrated in the treatise (all of them for a latitude of 36°). I use the declination D as al-Marrākushī; when positive the sundial is declining toward the east, and when negative toward the west. Note that Najm al-Dīn employs $d = 90° - D$ instead. (We prefer D for the following descriptions because it allows us to distinguish between eastern or western declinations.)

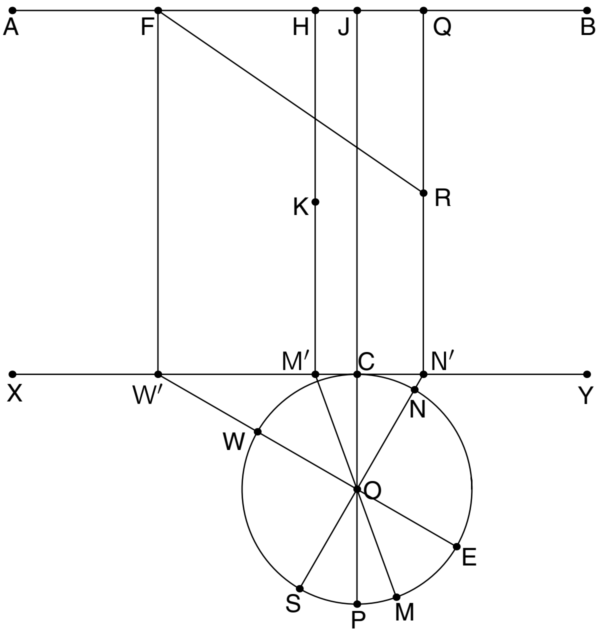

FIG. 4.4. Construction of a declining vertical sundial

- Ch. 109: $D = -40°$, seasonal hours 6–12, *ʿaṣr*(see Fig. 4.10).

- Ch. 110: $D = 50°$, seasonal hours 0–6 (see Fig. 4.10).

- Ch. 114: $D = -45°$, equal hours 7–0 before sunset, *ʿaṣr*.

- Ch. 116: $D = -45°$, seasonal hours 6–12 [incomplete: only hours 6 and 12 are traced], markings for the altitude (unnumbered) and the azimuth (30 north, 25, ..., 90 south) – see Fig. 4.5 (with hour-lines and *ʿaṣr* added, azimuth and altitude markings at each 10°).

Sundials on columns

The procedure for constructing sundial markings on a column with fixed gnomon (Ch. 93) is identical to that for declining plane sundials. One should be aware, however, that on the surface of a column it is not possible to draw markings with the same range as on a plane surface. The range of azimuths for which the shadow can fall on the column will be a function of the ratio between the gnomon length g and the radius of the column r. It is easy to

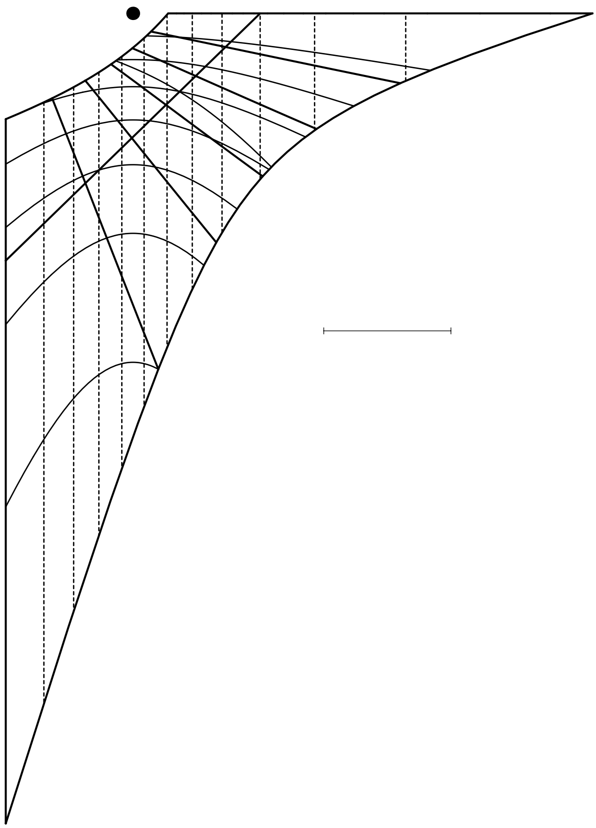

FIG. 4.5. A declining sundial ($d = -45°$) with altitude and azimuth markings, illustrated in Ch. 116

show that limit values of the azimuth will be given by

$$a_{\text{lim}} = \arcsin\left(\frac{r}{r+g}\right) \pm D\,.$$

A three-dimensional representation of a cylindrical sundial for latitude 36°, with gnomon declining 25° toward the east, is shown in Fig. 4.6.

al-Marrākushī describes a different kind of cylindrical sundial, on which the gnomon is movable but the cylinder is fixed with respect to the cardinal directions.[41] The hour- and day-lines are constructed by dividing the circum-

[41] al-Marrākushī, *Jāmiʿ*, I, pp. 334–336 [*fann* 2, *qism* 3, *faṣl* 30]; Sédillot, *Traité*, pp. 586–589; cf. Schoy 1913, pp. 38–39, Schoy 1923, pp. 73–74, and Delambre 1819, p. 517.

FIG. 4.6. Cylindrical sundial for latitude 36° with gnomon deviating eastwards from the meridian by 25°. The radius of the cylinder is three times the gnomon length.

ference of the cylinder into 360 divisions corresponding to the azimuth, and by marking the vertical shadow lengths for each hour at the equinox and solstices underneath the appropriate azimuth division. Najm al-Dīn describes the construction of an identical sundial in Ch. 94, and refrains from including an illustration because he judges impossible to represent a three-dimensional figure on the page without distortion of the hour-lines.

To use this sundial the gnomon, with a plumb-line attached at its base, has to be rotated towards the sun until the shadow falls exactly on the plumb-line: the extremity of the shadow will indicate time as well as the solar declination. Other variants are described in which the cylinder is perpendicular to various planes (meridian, prime vertical or a plane of arbitrary inclination with respect to either of them, or both of them).[42]

4.3.4 *Inclined sundials*

Before considering Najm al-Dīn's surprisingly simple method, a succinct survey of the methods proposed by several of his predecessors is appropriate. The first author to treat inclined sundials in the Arabic literature was probably Ḥabash, but his treatise is lost. The earliest extant work giving a full treatment of inclined sundials is the treatise by Thābit ibn Qurra already mentioned. Thābit gives the horizontal coordinates (altitude and azimuth) of the sun in the plane of an inclined sundial in terms of the horizontal coordinates in the plane of the corresponding vertical sundial which is *perpendicular* to it.[43] He also gives the Cartesian coordinates on the inclined sundial in terms of those on the declining sundial (equivalent to equations 4.8 above).[44] A third possibility is also mentioned, namely, that of considering the surface of the sundial as the horizon of a different locality, and to determine, through spherical trigonometry, the latitude and longitude difference of the locality in question.[45] The problem is then reduced to that of constructing a horizontal sundial for that locality; one must however take into account the longitude difference in order to accordingly shift the time of day corresponding to each hour-line. But Thābit preferred not to pursue the idea, because the other methods he presents are "simpler and more appropriate". Ibrāhīm ibn Sinān decided to follow the lead suggested by his grand-father Thābit. He derived cumbersome formulæ for the latitude ϕ' and longitude difference ΔL of the locality whose horizon is parallel to a given sundial plane, by achieving a laborious demonstration through spherical trigonometry (using the Chord function and the theorems of

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[42] al-Marrākushī, *Jāmiʿ*, I, pp. 337–345 [*fann* 2, *qism* 3, *faṣl*s 31 to 35]; Sédillot, *Traité*, pp. 586–601.

[43] Morelon 1984, pp. 156–157, 281–282.

[44] *Ibid.*, pp. 164, 290–291.

[45] *Ibid.*, pp. 150–151.

Menelaus).[46]

Now to al-Marrākushī's mathematical treatment of inclined sundials.[47] For inclined sundials with perpendicular gnomons al-Marrākushī adopts the idea already proposed by Thābit and Ibrāhīm of computing ϕ' and ΔL, but his formulæ are much more elegant than those given by Ibrāhīm.[48] One should successively find $\alpha = \arcsin(\sin i \sin D)$, $\beta = \arcsin(\cos i / \cos\alpha)$, and $\gamma = |\beta - \bar{\phi}|$. The latitude ϕ' and longitude difference ΔL are then simply given in terms of these quantities as:

$$\sin\phi' = \sin\gamma\,\cos\alpha \qquad \text{and} \qquad \sin\Delta L = \sin\alpha/\cos\phi' .$$

A different approach is proposed by al-Marrākushī for inclined sundials with gnomons parallel to the horizon,[49] which involves computing the position of the shadow on the inclined surface in terms of the Cartesian coordinates on the corresponding vertical sundial. In Fig. 4.7 $ABHE$ is a vertical plane, and $ACGE$ a plane of inclination $\angle BAC = i$. Consider a horizontal gnomon EF of length 12. We have $EH = 12\cot i$ and $EG = 12\csc i$. The shadow falls on the vertical surface $ABHE$ at L and on the inclined surface $ACGE$ at P. Sought is the position of point P in terms of the Cartesian coordinates of the shadow on the vertical surface $\xi_v = EK$ and $\eta_v = KL$. Clearly, point P is located in plane $KFGM$. Furthermore,

$$KF = \sqrt{EF^2 + EK^2} = \sqrt{12^2 + \xi_v^2}$$

and

$$KG = \sqrt{KF^2 + FG^2} = \sqrt{12^2 + \xi_v^2 + (12\cot i)^2} .$$

[46] See Luckey & Hogendijk 1941/1999, pp. 158–163 (text and translation), 52–54 (commentary). The equivalent formulæ for ϕ' and ΔL, using modern trigonometric functions instead of chords, and assuming the same definition of the declination D and inclination i as al-Marrākushī, would be:

$$\sin\phi' = \cos i\,\cos(\phi + x)/\sin x \quad \text{where} \quad \tan x = \cot i/\cos D$$

$$\tan\Delta L = \tan y/\sin\phi \quad \text{where } y \text{ should be solved in} \quad \sin y/\sin(D - y) = \tan\phi\,\tan i .$$

Ibrāhīm does not explain how to solve this, but the reader will easily check for himself or herself that y can be expressed as

$$\tan y = \frac{\tan\phi\,\tan i\,\sin D}{1 + \tan\phi\,\tan i\,\cos D} .$$

[47] The simple cases of sundials parallel or perpendicular to the plane of the celestial equator, which al-Marrākushī treats in details, are omitted.

[48] al-Marrākushī, *Jāmiʿ*, I, pp. 171:12–173:5 [*fann* 1, *faṣl* 80]; Sédillot, *Traité*, pp. 338–340. Concrete applications of this method are found in *fann* 2, *qism* 3, *faṣl* 7 (Sédillot, pp. 531–532), *faṣl* 8 (*ibid.*, pp. 533–534) and elsewhere. Schoy misunderstood the procedure and gave an erroneous demonstration (see Schoy 1923, p. 69, equations I to V).

[49] In practice al-Marrākushī also uses this second method for sundials with perpendicular gnomons (e.g. in *fann* 2, *qism* 3, *faṣl* 9).

For the distance KP, prolonging line KM to M', with $MM' = KL$, gives a parallelogram $FLM'G$. Triangle KPL is similar to triangle KGM', so that $KP : KL = KG : KM' = KG : (KM + KL)$. Hence

$$KP = KL\,\frac{KG}{EH + KL} = \frac{\eta_v\,\sqrt{12^2 + \xi_v^2 + (12\cot i)^2}}{\eta_v + 12\cot i}\,,$$

which is the formula given, without proof, by al-Marrākushī.[50] The coordinates KE and KP are called the "distance" (*buʿd*) and "auxiliary shadow" (*al-ẓill al-mustaʿmal*).

An almost identical procedure is presented in an extract of an anonymous treatise on gnomonics appended to the unique copy of Thābit's treatise.[51] For the sake of convenience its author is called 'Pseudo-Thābit'. This extract concerns the construction of an inclined sundial called the *maknasa*. In order to construct this sundial, Pseudo-Thābit considers the distance GP instead:

$$GP = KG - KP = KG\left(1 - \frac{KL}{KM + KL}\right) = \frac{12\cot i\,\sqrt{12^2 + \xi_v^2 + (12\cot i)^2}}{12\cot i + \eta_v}\,.$$

Najm al-Dīn's method

Najm al-Dīn determines, as Thābit already did,[52] the Cartesian coordinates on the inclined sundial in terms of the Cartesian coordinates of the corresponding vertical sundial with the same declination, with the difference that he considers a perpendicular gnomon instead of the horizontal one of his predecessor. The vertical coordinate η can be computed from the coordinate η_v on the corresponding vertical sundial:

$$\eta = \mathrm{Cot}\{\mathrm{arcCot}\,\eta_v \pm i\}\,,^{53} \tag{4.9}$$

the idea being the same as with a conical sundial (see Section 3.2.1). The formula for the horizontal coordinate is given in the first paragraph of Ch. 112 as

$$\xi = \xi_v\,\frac{\eta_v + \mathrm{Cot}\,i}{\mathrm{Csc}\,i}\,, \tag{4.10}$$

which is *erroneous*. It should be

$$\xi = \xi_v\,\frac{\mathrm{Csc}\,i}{\eta_v + \mathrm{Cot}\,i}$$

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50 al-Marrākushī, *Jāmiʿ*, I, pp. 173:5–174:8 [*fann* 1, *faṣl* 81]; Sédillot, *Traité*, pp. 340–341. Applications of this method are given in *fann* 2, *qism* 3, *faṣl* 8 (Sédillot, pp. 535–537), in *faṣl* 9 (*ibid.* pp. 541–545), and elsewhere.

51 Morelon 1984, pp. 165–167.

52 Morelon 1984, pp. 164, 290–291.

53 The sign is positive when the shadow falls below the gnomon ($90° - \mathrm{arcCot}\,\eta_v \geq i$) negative when it falls above ($90° - \mathrm{arcCot}\,\eta_v \leq i$).

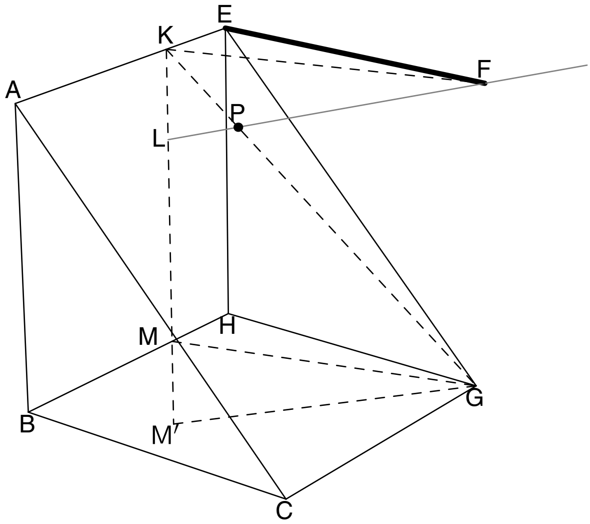

FIG. 4.7. Construction of an inclined sundial with horizontal gnomon

instead.[54] In Ch. 111 a graphical construction of this quantity is given, but it is twice faulty.[55]

Astonishingly, most diagrams of inclined sundials in Najm al-Dīn's treatise are *correctly* drawn. This means that the erroneous formula given in the treatise was not used by the person who made the illustrations. Could it be that more than one person was at work? Or that some assistants, students or later copyists have completely corrupted a text which, originally, contained the correct procedure? In any case, we observe that a systematic error affecting the text cannot be detected on the illustrations.

Application to horizontal sundials. An application of the above procedure is found in Ch. 102, where a horizontal sundial is treated as a sundial of inclination $i = 90°$ with respect to a vertical sundial facing south. Najm al-Dīn gives for this sundial $\eta = \mathrm{Tan}(\mathrm{arcCot}\,\eta_v)$, which derives from his formula 4.9, but he could have expressed it more simply as $12^2/\eta_v$. For the distance he gives $\xi = \frac{\eta_v}{12}\,\xi_v$, which derives directly from his erroneous formula 4.10. Ch. 102 also includes a table of the Cartesian coordinates of a horizontal sundial, which was *not* computed by means of the above formulæ, even though

[54] It is not difficult to demonstrate its equivalence with equation 4.7 above.

[55] The procedure is equivalent to $\xi = \xi_v\,\frac{\mathrm{Cot}\{\mathrm{arcCot}(\eta_v) \pm i\}}{\mathrm{Csc}\,i}$, which is absurd.

its entries are particularly crude. The axis of the ξ-coordinate, from which η is counted toward south, is displaced from the location of the gnomon toward the north by a certain distance, which is such that the northernmost corners of the sundial are located on this axis. The use of 'displaced functions', i.e., the addition of a constant to make a particular function always positive, is frequently attested in Islamic *zīj*es.[56]

Najm al-Dīn's illustrations of inclined sundials

- Ch. 108: (1) $D = 90°$, $i = 45°$, seasonal hours 0–6; (2) $D = -90°$, $i = 45°$, seasonal hours 6–12, *ʿaṣr* (see Fig. 4.11).
- Ch. 111: $D = -40°$, $i = 50°$, seasonal hours 6–12, *ʿaṣr*.
- Ch. 112: $D = 40°$, $i = 10°$ facing the ground, seasonal hours 0–3.
- Ch. 115: $D = -45°$, $i = 30°$, equal hours 8–0 before sunset (see Fig. 4.8 and Plate 14).
- Ch. 119: $D = 80°$, $i = 10°$ facing the ground, equal hours 0–4 since sunrise, markings for the altitude (6, 12, ..., 54 [! in fact 42 is the limit]) and the azimuth (30 north, 20, ..., 60 south) (see Fig. 4.9).
- Ch. 120: purports to be for $D = -45°$, $i = 60°$, seasonal hours 6–12 [numbered 6–0!], azimuth lines (30 north, 20, ... 90 south). The illustration, however, diverges not only from the sundial corresponding to these parameters, but also from any other possibility.
- Ch. 121: $D = -45°$, $i = 30°$ facing the ground, seasonal hours 11–12 [the angle between both hour-lines is much too large].

4.3.5 *Composite sundials on adjacent surfaces*

Compositions of two sundials on 'diptychs', i.e., on two adjacent surfaces making a certain angle to each other, are mentioned by several Muslim authors on gnomonics. Not fanciful creations, they are very useful applications of gnomonics. Two vertical sundials can be found on both sides of the exterior walls of a building, near the southernmost corner, or, inversely, in the northernmost corner of the walls enclosing an open courtyard. al-Marrākushī calls the first kind, where the eastern surface is facing eastward and the western surface westward, a "winged" (*mujannaḥa*) sundial, and the second case a "mutually corresponding" (*mutakāfiʾ*) sundial.[57] The latter will only

[56] See King & Samsó 2001, pp. 38, 41, 61 and esp. p. 80.

[57] al-Marrākushī, *Jāmiʿ*, pp. 350:13–352:8 [*fann* 2, *qism* 3, *faṣl* 41]; Sédillot, *Traité*, pp. 609–612. Cf. Schoy 1923, pp. 70–71.

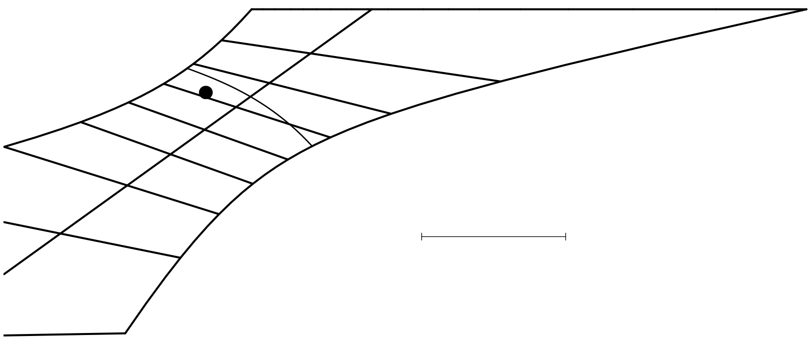

FIG. 4.8. An inclined sundial (with $D = -45°$, $i = 30°$) displaying equal hours before sunset, as illustrated in Ch. 115

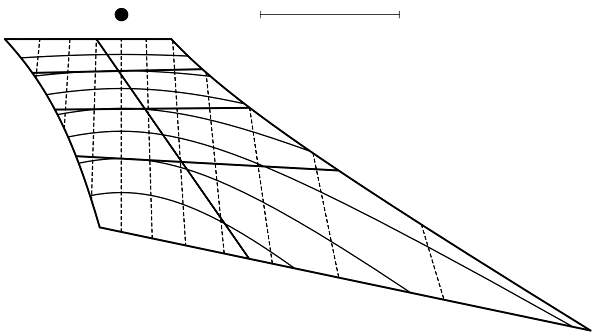

FIG. 4.9. A sundial inclined toward the ground (with $D = 80°$, $i = 10°$) displaying equal hours since sunrise, altitude curves and azimuth lines, as illustrated in Ch. 119

need one gnomon fixed at the corner and oriented toward the meridian: in this way the markings of both sundials will meet each other exactly at the corner.[58] Najm al-Dīn considers composite vertical sundials of the *mutakāfiʾ* variety in Ch. 110, and calls them simply *mawṣūla*, "connected". Three kinds are mentioned: those making an angle of 90°, those making an obtuse angle, called *maftūḥa*, "opened", and those making an acute angle, called *maghlūqa*, "closed". The sundial illustrated in Ch. 110 is chosen to complement that of Ch. 109, so that together they make a right angle. In Fig. 4.10 these two sundials are illustrated in a three-dimensional perspective.

The maknasa

Another interesting type of composite sundial is the *maknasa*, literally a "place in or under which wild animals shelter", which consists of two rectangular surfaces of the same inclination, adjacent at the top, thus resembling an inclined roof.[59] The most common variety has the junction of both surfaces aligned with the meridian, so that each inclined surface faces the east and west. al-Marrākushī mentions varieties set 'upside-down', with the eastern surface facing westward and the western surface eastward, and also includes *maknasa*s declining from the meridian.[60]

The earliest mention of the *maknasa* in Islamic sources is a short anonymous text probably from the ninth or early-tenth century entitled *ʿAmal al-rukhāma al-maknasa* (or perhaps better: *al-mukannasa*, shaped like a *maknasa*), which is preserved in MS Istanbul Aya Sofya 4830, f. 193r. This text – obviously extracted from a larger work on sundials – describes the construction of a *maknasa* aligned with the meridian and whose sides are inclined by 45°. Each side bears a gnomon of length 33 (!) *perpendicular* to the surface. The text is accompanied by a table which gives the polar coordinates ('azimuth' and 'shadow') with respect to the base of the gnomon of a series of points on the day-lines of Capricorn and Cancer, for seasonal hours 0 to 6 and for all quarters. The table is designed for the eastern side of the *maknasa*; the western side is symmetric. The entries in the tables are not extremely accurate, but in view of the mathematical complexity involved, the table is nevertheless

[58] Such a sundial is also described by Ibn al-Raqqām, with both surfaces declining by 45°: see Carandell 1988, pp. 285–286, 82–84, and 173–174 (with incorrect sundial markings on the illustration of p. 174).

[59] Sédillot (*Traité*, p. 611) – and after him Schoy (1923, p. 71) – read the word مكنسة as *miknasa* and accordingly translated it as "balai", i.e., "broom", which makes no sense in this context. Régis Morelon (1984, p. 291) has convincingly argued that the correct reading is in fact *maknasa*, feminine form of *maknas*, which means "covert, hiding-place into which wild animals enter to protect themselves". This word is related to the verb *kanasa*, one meaning of which is "to hail to its abode", speaking of wild animals. See Lane, *English-Arabic Lexicon*, *sub* كنس. The two surfaces of the sundial form a sort of triangular tent, similar (in shape or function) to a *maknas*.

[60] See the reference in n. 57.

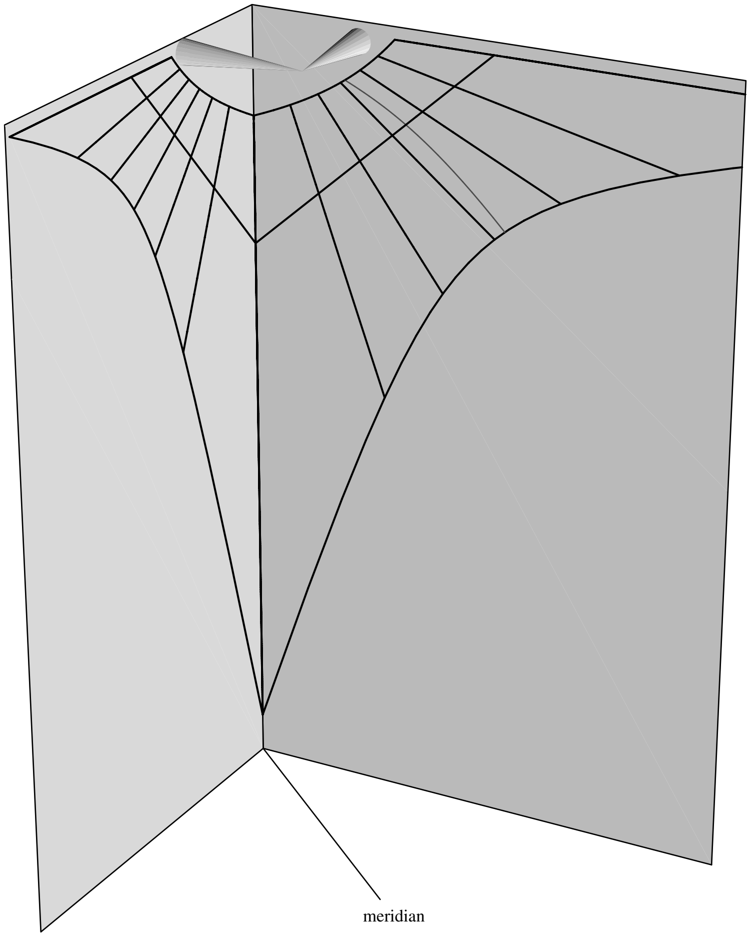

FIG. 4.10. Two connected (*mawṣūla*) declining sundials at a right angle

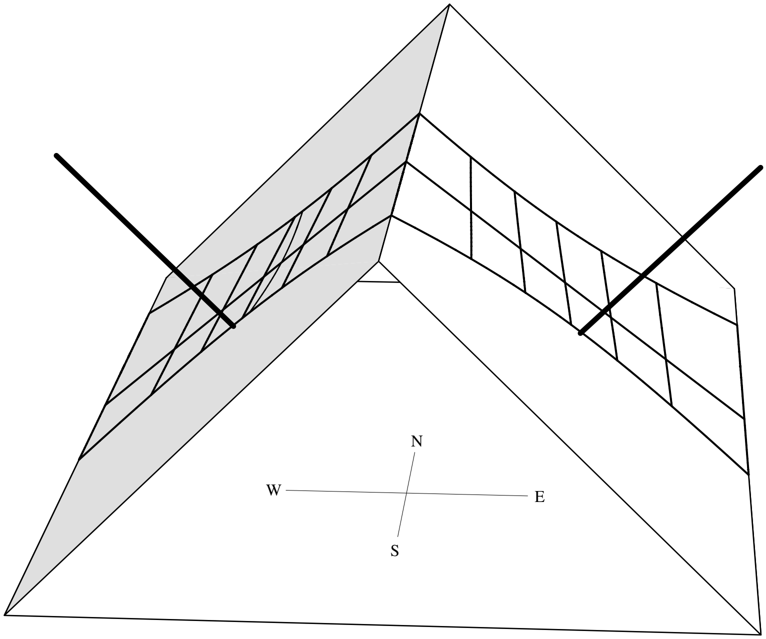

FIG. 4.11. The *maknasa*: a double sundial on a roof

remarkable, and it allows the construction of a fairly correct sundial. A first investigation reveals that the best fit occurs with a latitude of 34°, while 33° is also possible.[61] The only Muslim author prior to Thābit who is known to have composed a work on gnomonics dealing with inclined sundials is Ḥabash, so perhaps this text is an extract of his treatise listed in the *Fihrist*.[62]

A second testimony is the anonymous extract mentioned above by 'Pseudo-Thābit'. His *maknasa* is also oriented with the meridian, but its gnomon is horizontal. The table accompanying the text gives coordinates equivalent to *EK* and *GP* in Fig. 4.7.

Najm al-Dīn treats this sundial in Ch. 108. Unfortunately, the text is hopelessly corrupt, and the formulæ given for calculating the Cartesian coordinates in terms of those of a corresponding vertical sundial are incorrect. Yet the diagram of the markings on both sides, filling two folios, is excellent. On Fig. 4.11, I have represented them in three dimensions on the *maknasa*.

[61] I propose to publish the text together with an analysis of the table in a separate publication.
[62] See n. 7 above.

4.4 *Miscellaneous three-dimensional sundials*

4.4.1 *Hemispherical sundials*

Hemispherical sundials were widespread in Antiquity.[63] However, there are surprisingly few accounts concerning them in the Arabic technical literature. al-Marrākushī presents a sound, simple geometrical method for constructing some standard kinds. Najm al-Dīn could easily have reproduced the words of his predecessor. But blindly adhering to his philosophy of instrument-making, he chose instead a superfluous numerical procedure.

In the simple case of a concave hemispherical dial resting on its pole, Najm al-Dīn naively advocates constructing the hour-lines by marking on its inner surface the altitude and azimuth of each hour, for each zodiacal sign. He also describes a wooden quadrant whose radius coincides with the inner radius of the hemisphere, which facilitates the marking of those hour-lines on the spherical surface. His instructions end with the usual remark about the impossibility of illustrating a three-dimensional object.

The method put forward in the next chapter for constructing sundial markings on the outer surface of a convex hemisphere is, however, justified, as it can no longer rely on a 'natural' configuration. Najm al-Dīn employs a rather empirical method for constructing the markings on it, which is, as usual, requires a table of shadows and azimuth (on the horizon) and a three-dimensional geometrical construction. A ruler, which can be rotated freely, is fixed at the base of the gnomon on top of the cupola and is held horizontally. A thread is also attached at the top of the gnomon. To make a mark on the cupola corresponding to a certain shadow and azimuth, the ruler is rotated in the direction of this azimuth and the thread is stretched so that it intersects the graduation of the ruler at the shadow. The extension of this thread to the surface of the cupola will yield the desired mark.

4.4.2 *Staircase sundial*

An unusual sundial is described in obscure prose in Ch. 99. It consists of a series of stairs which are laid out in such a manner that whenever one hour passes before noon, the shadow of the gnomon jumps one step, and inversely in the afternoon. Unfortunately, Najm al-Dīn does not precisely tell us how to construct such a sundial, so we will not attempt at reconstructing one. The procedure may have been empirical rather than mathematical. This sundial calls to mind the ancient Egyptian 'zikkurat' time-telling device now preserved in Cairo.[64]

[63] See Drecker 1931, pp. 21–36; Gibbs 1976; Schaldach 1997.
[64] See Schaldach 1997, p. 22.

CHAPTER FIVE

TRIGONOMETRIC INSTRUMENTS

5.1 *The sine quadrant and the* dastūr

Although the morphology and use of the standard sine quadrant and of the related *dastūr* are relatively well-known,[1] their development in the Mamluk and Ottoman period, and the new applications of the instrument devised by later authors (mostly in a didactical context) are virtually unexplored. The astonishingly large number of *non-standard* trigonometric instruments of considerable ingenuity invented in these later periods are either unknown or have been largely ignored by specialists of instrumentation and of the history of Islamic science.[2] A new survey of Islamic trigonometric instruments is a *desideratum*, which cannot adequately be provided in the present study, for two reasons. First, Najm al-Dīn's treatment of trigonometric instruments is rather narrow and does not reflect the multiplicity and ingenuity of all kinds of trigonometric quadrants and grids invented by his contemporaries Ibn al-Sarrāj, Ibn al-Ghuzūlī and Ibn al-Shāṭir. Second, the literature on those non-standard instruments is unpublished and merits a separate study. I have, nevertheless, conducted a preliminary analysis of all available Mamluk texts on such instruments, which will be included in a forthcoming publication.

The sine quadrant (*al-rubʿ al-mujayyab*, or simply *al-jayb*) was invented in early ninth-century Baghdad and is probably to be associated with the well-known scientist al-Khwārizmī. A hitherto unpublished short treatise attributable to him describes its construction and use.[3] al-Marrākushī's testimony that some people referred to the sine function as "the khwārizmī sine" *al-jayb al-khwārizmī*, i.e. the sine (quadrant) of al-Khwārizmī, lends credence to this attribution.[4] The sine quadrant appears to have originally been intended as a

[1] The only available general study of the *dastūr* and the sine quadrant is still Schmalzl 1929, pp. 62–99, which contains some errors and is much outdated. The use of the sine quadrant is also treated in Würschmidt 1918, Würschmidt 1928, and Worell & Rufus 1944.

[2] Some of them are described, not always accurately, in Schmalzl 1929, pp. 100–112; some are also mentioned in King 1988. A trigonometric quadrant by Ibn al-Sarrāj is investigated in Charette 1999a.

[3] See Charette & Schmidl, "Khwārizmī".

[4] al-Marrākushī (*Jāmiʿ*, I, p. 39 [*fann* 1, *faṣl* 10]; cf. Sédillot, *Traité*, p. 120) informs us that "some people call this table the table of the *khwarizmī* sine (*wa-min al-nās man yusammī hādhā al-jadwal al-jayb al-khwārizmī*)". His *summa* contains other instances where it is referred to the

graphical device for finding the time as a function of the altitude by means of the universal approximate formula.[5] The original sine quadrant that was invented in the ninth century bore an altitude scale along its rim and a set of parallel lines, either horizontal or vertical, drawn from equal divisions of the altitude scale to one of the radii, parallel to the other radius. Later authors often called this type the "nonagesimal sine quadrant" (*al-jayb al-tisʿīnī*), because its radial scale has 90 divisions. Another variant of the sine quadrant is characterised by an orthogonal grid of 60 equally-spaced horizontal and vertical lines, like modern graph paper; this was called the "sexagesimal sine quadrant" (*al-jayb al-sittīnī*). A trigonometric grid of this kind is illustrated in the *Zīj al-ṣafāʾiḥ* of Abū Jaʿfar al-Khāzin (*fl.* tenth c.), and corresponds to one side of the European instrument called the *sexagenarium*.[6] The instrument can also bear various other markings, such as semicircles for finding the sine, quarter circles for finding the declination, lines for finding the shadow, curves of the altitude at the beginning and end of the *ʿaṣr* (see Section 3.5.4 above) or for the solar altitude in the azimuth of the *qibla*. We should also mention a complex universal instrument by Ḥabash al-Ḥāsib, which features numerous sine quadrants and other trigonometric scales.[7]

Radial lines or quarter circles were sometimes added to the basic design of the sexagesimal sine quadrant (see Fig. 5.4): these markings, however, were common features of the closely related trigonometric instrument called the *dastūr*, which is simply a circular grid containing the markings of four sine quadrants (see Fig. 5.2). Some authors interpreted it in a less abstract sense as representing an orthogonal projection of various circles of the sphere.[8] Many authors use the terms '*dastūr* quadrant' or 'sine quadrant' indiscriminately.

Najm al-Dīn's sine quadrant (Ch. 58 – see Fig. 5.4) is more akin to the *dastūr* than to the classical sine quadrant: it bears indeed the same markings (lines of sines and cosines, radial lines and concentric arcs with radii corresponding to the sines) as al-Marrākushī's *dastūr* (see Fig. 5.1).[9] Yet Najm al-Dīn's version of the *dastūr* (Ch. 60) is lacking the concentric circles and radial lines. al-Marrākushī's sine quadrant (called *rubʿ al-dastūr*) is very similar to that of Najm al-Dīn, with the exception of lacking radial lines and the addition of curves for the beginning and end of the *ʿaṣr* prayer and a circular

sine, shadow and declination (scales) of al-Khwārizmī: see al-Marrākushī, *Jāmiʿ*, I, p. 250 [*fann* 2, *qism* 2, *faṣl* 9] (= Sédillot, *Traité*, p. 465), and *ibid.*, II, p. 200 [*fann* 3, *bāb* 5].

[5] The earliest texts on the sine quadrant give procedures for finding the time that are derived from the approximate formula: the oldest text, probably attributable to al-Khwārizmī, contains, however, an erroneous procedure (see Charette & Schmidl, "Khwārizmī"). A Latin text from the late tenth century also describes a form of sine quadrant for finding the time in seasonal hours: see Millás 1932. See also Lorch 1981, Lorch 2000a, and King, *SATMI*, VIIa, §§ 8–10.

[6] See King, *SATMI*, VIII, § 6.1.

[7] See Charette & Schmidl 2001.

[8] Schmalzl 1929, pp. 63–68.

[9] al-Marrākushī, *Jāmiʿ*, I, pp. 374:16–375:12; cf. Sédillot, *Mémoire*, pp. 87–88.

arc of radius 24 for finding the declination (see Fig. 5.3).[10] One unusual and interesting feature of al-Marrākushī's sine quadrant is the marking on its surface of fixed stars represented by dots with positions defined in polar coordinates by ($\rho = \mathrm{Cos}\,\Delta, \theta = \alpha'$).[11] al-Marrākushī describes another trigonometric instrument of considerable interest.[12] It consists of a semicircular plate of hard wood, which bears on one of its faces an orthogonal equidistant grid and equidistant concentric semicircles; the outer scale is numbered anticlockwise from 0 to 180, and a scale along the diameter is accordingly numbered from 0 to 120 (see Fig. 5.5). A movable cursor (*al-majra*) with a small index (*ziyāda*) runs along the horizontal axis. A thread is attached at the centre and a second one at the tip of the index of the movable cursor. Two sights (*hadafa*) are fixed at both extremities of the diameter. Between them, on the lateral rectangular surface of the instrument, a sundial is drawn as on the 'Fazārī balance', each sight serving as a gnomon (see Section 3.3.2). The back of the instrument displays a table of oblique ascensions as on the "Fazārī balance" (see Section 6.2); it also bears two altitude scales and a series if dots representing the fixed stars, marked in the same manner as on the sine quadrant.[13]

5.2 *Universal horary quadrants*

Universal horary quadrants are graphical devices specifically designed for finding the time of day in terms of the instantaneous and meridian altitude by means of the universal approximate formula for timekeeping given in equation 1.1 (p. 22). But trigonometric instruments in general are perfectly well suited to solve formulæ of this type, and we have seen in the previous section that the sine quadrant probably originated out of an attempt to solve graphically the problem of finding the time from the instantaneous altitude by means of the above formula. They can thus be considered as instruments that yield the quantity $\arcsin(\sin\theta_1 / \sin\theta_2)$ when fed in with arguments θ_1 and θ_2, which is indeed one of the basic operations performed by sine quadrants. This is the reason why universal horary quadrants appear in this chapter. Universal horary quadrants, as for the sine quadrant, were apparently devised in ninth-

[10] al-Marrākushī, *Jāmiʿ*, I, pp. 371:3–374:15; cf. Sédillot, *Mémoire*, pp. 82–87.

[11] As far as I know, such marks for the stars are not found on any surviving sine quadrants. The reason is simply that sine quadrants were usually featured on the back of astrolabe quadrants, which already include markings for the fixed stars. al-Marrākushī's sine quadrant, probably following some otherwise unknown Andalusi tradition, featured on the back of an horary quadrant.

[12] al-Marrākushī, *Jāmiʿ*, I, pp. 377–378 [*fann* 2, *qism* 4, *faṣl* 4]; cf. Sédillot, *Mémoire*, pp. 107–109.

[13] The use of the instrument is explained in al-Marrākushī, *Jāmiʿ*, II, pp. 201–202 [*fann* 3, *bāb* 6]; cf. Sédillot, *Mémoire*, p. 109. The procedure for finding the hour-angle, especially the first operation for constructing the quantity $\mathrm{Vers}\,D$, is not quite clear. Sédillot's paraphrase is moreover lacunary.

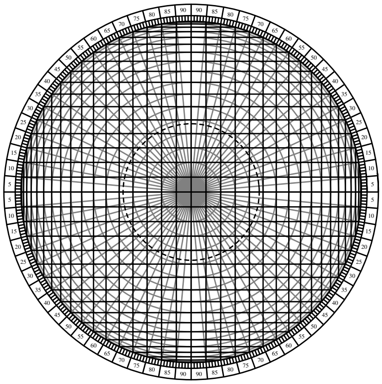

FIG. 5.1. al-Marrākushī's *dastūr*

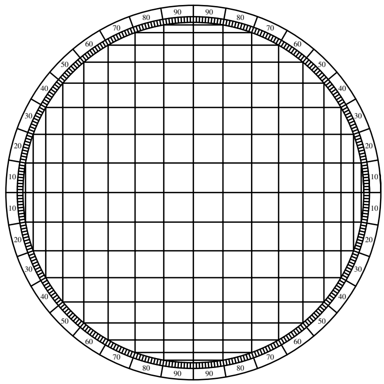

FIG. 5.2. Najm al-Dīn's *dastūr*

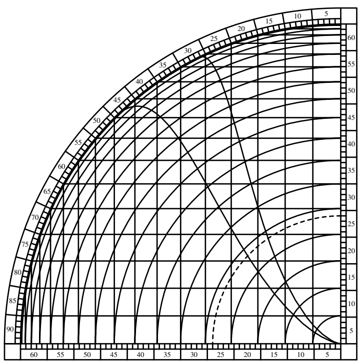

FIG. 5.3. al-Marrākushī's sine quadrant

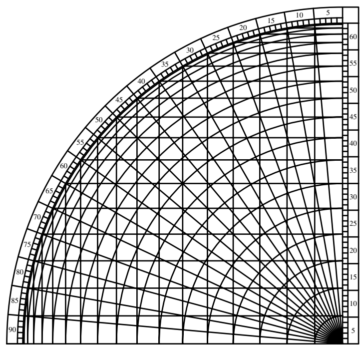

FIG. 5.4. Najm al-Dīn's sine quadrant

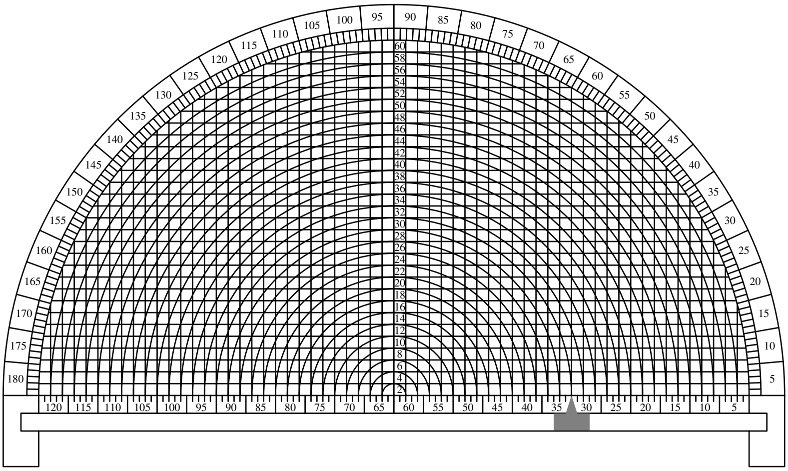

FIG. 5.5. al-Marrākushī's trigonometric semicircle

century Baghdad, and the earliest text on its use has recently been published for the first time.[14]

There exist two types of universal horary quadrants. On the first one the hour-lines are circular arcs whose centres are located on the meridian line or its extension, intersecting the outer scale at each 15° and converging at the centre of the quadrant. This type is very well-known, for it figures on the back of countless astrolabes, especially those originating from Western Islam and Europe, and on several other instruments, especially the quadrant known in the medieval West as *quadrans vetus*.[15] At least one author from the fourteenth century, namely Ibn al-Sarrāj, classified this universal horary quadrant, or more generally its underlying design, as one particular kind of sine quadrant.[16] It has been suggested that the universal horary quadrant of this type could have been derived from the sine quadrant.[17] The second variety of universal horary quadrant is fully equivalent to a sine quadrant on which the hour-lines are radii to each 15° of the altitude scale.[18] The use of both quadrants is illustrated in Fig. 5.6.

Both versions of the universal horary quadrant are described by Najm al-

[14] See King 2002 and King, *SATMI*, VIIb.

[15] On this type of horary quadrant, see King 2002, and idem, *SATMI*, VIII, and the references there cited; see also Lorch 1981 (where the underlying formula is unhappily derived in terms of the hour-angle) and Archinard 1990.

[16] MS Princeton Yahuda 296, ff. 8v–10v. Cf. Charette 1999a, p. 27, n. 18.

[17] Lorch 1981.

[18] See Millás 1932; Lorch 1981, p. 118; King 2002 and idem, *SATMI*, VIIa, § 9.4.

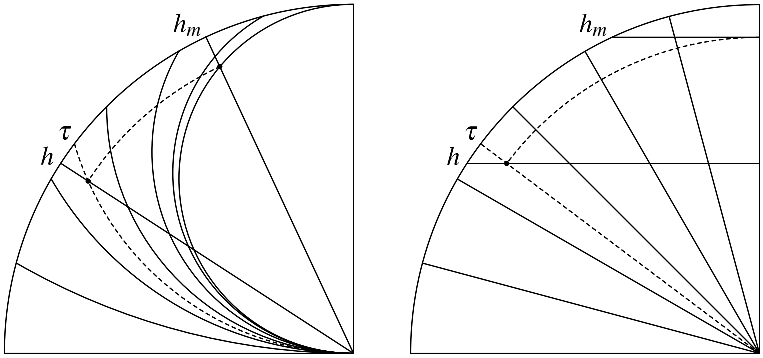

FIG. 5.6. The use of both types of universal horary quadrants

Dīn. His version of the first type (Ch. 57) also includes circular arcs for each third of an hour (drawn in red in **D**): see Fig. 5.7. It is possible to construct these circular arcs by trial and error with the compass, but Najm al-Dīn also gives the radii of the corresponding circles for hours 1 to 6. This radius can be found with the formula

$$\rho_i = \frac{R^2}{2\,\mathrm{Sin}(15\,i^\circ)} = 30\csc(15\,i^\circ)\,.$$

Najm al-Dīn gives the radii for hour-lines 1 to 6 as 120, 60, 42;25, 37;4, 31;4 and 30, whereas the accurate values are 115;55, 60, 42;26, 34;38, 31;03 and 30.[19] His values for the first and fourth hour-lines are clearly in error. For the first hour he obviously used the approximation $\mathrm{Sin}\,15^\circ \approx 15$ (as $60^2/30 = 120$), but the approximations for other multiples of 15° do not yield the other entries. He claims that his value for $\rho_4 = 37;4$ corresponds to $\mathrm{Chd}(90^\circ/5)$, whereas it actually corresponds to $\mathrm{Chd}(\frac{2}{5}\,90^\circ) = 37;5$; yet it is not apparent what motivated this computation. He also claims that $\rho_5 = 31;4$ corresponds to $\mathrm{Chd}(90^\circ/6)$, but this value corresponds to $\mathrm{Chd}(90^\circ/3) = 31;3$ instead.[20]

The universal horary quadrant with radial hour-lines in Ch. 74 has a semicircle for finding the sine of the meridian altitude, labelled 'arc of the meridian altitudes' (*qaws al-ghāyāt*), as well as a curve of the *ʿaṣr*. The semicircle facilitates the task of setting the bead to the Sine of the meridian altitude: if the thread is placed on the outer scale at the meridian altitude and the bead is set at its intersection with the semicircle, the distance of the thread from the centre will be the Sine of the meridian altitude. The rest of the operation is as in Fig. 5.6.

[19] al-Marrākushī also gives such a table, whose entries are accurate apart from the first entry, given as 115;53: see al-Marrākushī, *Jāmiʿ*, I, p. 363.

[20] The latter yields the correct value for ρ_5 because of the identity $1/\cos(15^\circ) = 4\sin(15^\circ)$.

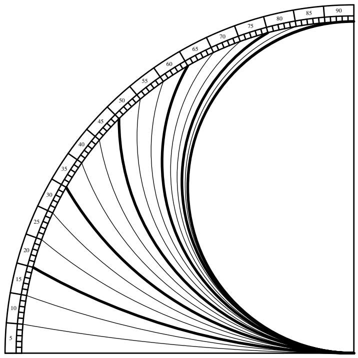

FIG. 5.7. Universal horary quadrant with circular hour-lines

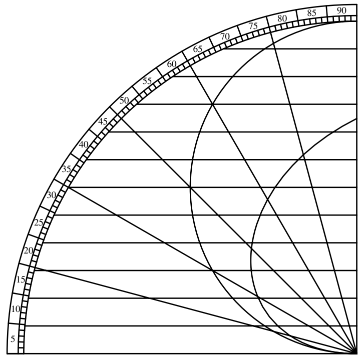

FIG. 5.8. Universal horary quadrant with radial hour-lines

The construction of the curve for the *ʿaṣr* is not explained in the text, but its form on the illustration suggests that it is identical to curve no. 2 described in Ch. 77 (see Fig. 3.49 on p. 179). Another marking for the *ʿaṣr* is mentioned in the text, consisting of a straight line from the beginning to the end of the outer scale. Its use is not clear.

5.3 *The quadrant with harp markings*

The unusual quadrant presented by Najm al-Dīn in Ch. 56 is in fact a simple variant of an instrument whose construction and use are already described in detail by al-Marrākushī in his *summa*. Since it has never been explained appropriately in the secondary literature, I shall first examine the standard version of the instrument according to the thirteenth-century Egyptian source.

5.3.1 *al-Marrākushī's 'figure for finding the hour-angle'*

The trigonometric 'figure for finding the hour-angle', as al-Marrākushī calls it (*shakl yuʿlam bihi al-dāʾir min al-falak*), is a 'materialization' of a standard graphical procedure for finding the time from the altitude on a sine quadrant.[21] The instrument facilitates the graphical computation of the hour-angle from the altitude and the meridian altitude, using the following *accurate* formula of

[21] al-Marrākushī, *Jāmiʿ*, I, pp. 357:16–359:20 (construction) [*fann* 2, *qism* 4, *faṣl* 1] and II, p. 150:1-12 [*fann* 3, *bāb* 3]; cf. Sédillot, *Mémoire*, pp. 59–64.

Indian origin:[22]

$$\mathrm{Vers}\, t = \mathrm{Vers}\, D \left\{ \frac{\mathrm{Sin}\, h_m - \mathrm{Sin}\, h}{\mathrm{Sin}\, h_m} \right\}.$$

Construction. al-Marrākushī's instructions can be summarised as follows:

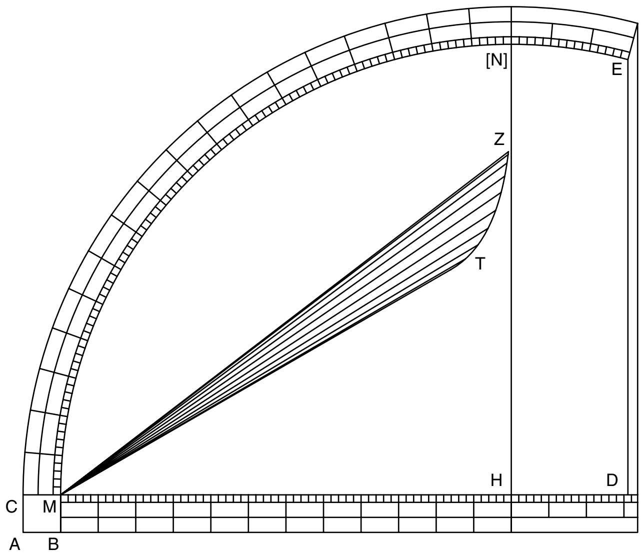

FIG. 5.9. al-Marrākushī's construction of the quadrant for finding the hour-angle

1. Take a rectangular plate with ratio length : width $\approx$ Vers$D$: R (when $\phi = 30°$ this ratio is about 6 : 5), and leave some extra space in width and in length in order to draw the scales. Let the extra length be AB and the extra width be AC.

2. Trace CD parallel to AB and BM parallel to CA, cutting CD at M. Divide MD in as many equal parts as the Versed Sine of the maximal half-arc of daylight. Number the scale from M to D at each 5 divisions. Make also a scale for the Sine from H to M with sixty numbered divisions.

3. Trace arc ME centred at H, E being near the right-hand margin of the plate, and divide it into as many parts as the maximal half-arc of daylight. Number this scale from M to E, and number also the arc of altitude from N to M.

4. Trace vertical lines parallel to DE for the Sines, from each subdivision of segment MD up to arc ME.

[22] On this formula, see Debarnot 1985, p. 37 and Charette 1998, p. 27.

5. On scale MD measure $\mathrm{Sin}\, h_m(\delta = \varepsilon)$ and trace an "invisible" (*wahmī*[23]) vertical line parallel to DE.

6. Trace an arc of radius MD centred at M and going from D to the "invisible" line, and let this arc be DZ. Trace line MZ. We have $MZ = \mathrm{Vers}\, D(\varepsilon)$.

7. Likewise measure $\mathrm{Sin}\, h_m(0)$ on MD and trace an "invisible" vertical line. Draw an arc centred at M of radius 60 from H to that vertical line, and let it be arc HT. Trace line MT (we have again $MT = \mathrm{Vers}\, D(0)$). Repeat this operation for intermediate values of the declination, for any interval desired. Join the extremities of the declination lines to form a curve ZT.

8. Trace circular arcs centred at M going from each fifth subdivision of scale MD to line MZ (optional, but useful when the thread is missing).

9. Mark some fixed stars in the same manner, that is, with a dot whose distance from M measures $\mathrm{Vers}\, D(\Delta)$ and whose horizontal coordinate is $\mathrm{Sin}\, h_m(\Delta)$. Indicate also the value of their right ascensions next to them.

On this instrument, a day-line for declination δ also serves declination $-\delta$. Whereas al-Marrākushī omits this important property, the day-lines on the figure in both copies of Najm al-Dīn's treatise are labelled with all appropriate zodiacal signs. To see the validity of this point, observe that

$$\mathrm{Cos}\angle QMP = \frac{R\ \mathrm{Sin}\, h_m}{\mathrm{Vers}\, D} = B(\phi, \delta) = \frac{\mathrm{Cos}\, \phi\ \mathrm{Cos}\, \delta}{R},$$

which is a symmetric function of δ.[24]

Use. To determine the hour-angle t from the meridian altitude h_m and the instantaneous altitude h, measure arc $h_m = NL$ on the scale of the quadrant, and also $h = NK$, so that $HX = \mathrm{Sin}\, h_m$ and $HY = \mathrm{Sin}\, h$ (see Fig. 5.10). Then on scale MH subtract HY from HX so that $MS = XY$ measures $\mathrm{Sin}\, h_m - \mathrm{Sin}\, h$. Let $MP = \mathrm{Vers}\, D$ be the corresponding day-line, with $MQ = HX = \mathrm{Sin}\, h_m$. From point S project vertically up to point R on line MP. With the thread, report the radius MR on the horizontal scale at W and from there, project vertically up to point Z on arc ME. Arc NZ will then measure t. It is not difficult to verify this, for

$$MR : MS = MP : MQ$$

$$\text{and} \qquad MR = \mathrm{Vers}\, D\ \frac{\mathrm{Sin}\, h_m - \mathrm{Sin}\, h}{\mathrm{Sin}\, h_m} = \mathrm{Vers}\, t,$$

and since $MW = \mathrm{Vers}\, t$ we have $NZ = t$. The same construction on a sine quadrant is described in an anonymous text from the ninth or tenth century.[25]

[23] See the remark on p. 254 , n. 1.

[24] On the auxiliary function $B(\phi, \delta)$, see King, *SATMI*, I, § 6, and Charette 1998, pp. 27–28.

[25] Published and analysed in Lorch 2000a, pp. 267–270. The procedure in this text assumes $\mathrm{Vers}\, D \leq R$ (equivalent to $\delta \leq 0$ for northern latitudes); no word is said about situations when this is not the case.

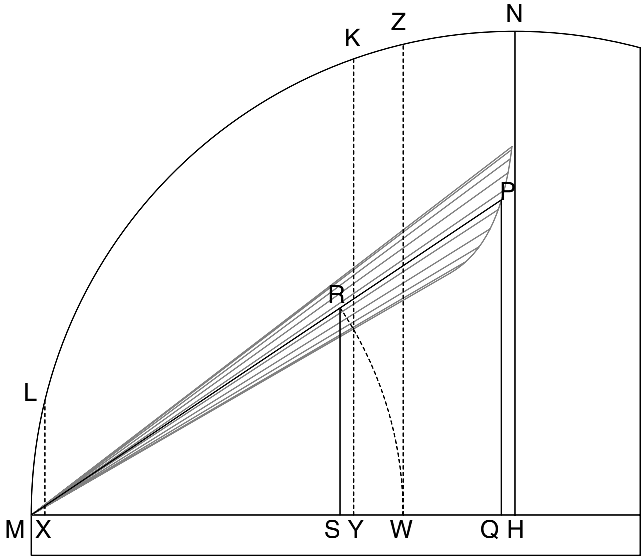

FIG. 5.10. Principle of the quadrant for finding the hour-angle

5.3.2 *Najm al-Dīn's version*

The procedure proposed by Najm al-Dīn in Ch. 56 is essentially the same as that of al-Marrākushī, even though it is expressed – as should be expected – in a much more concise manner. Najm al-Dīn did, however, introduce a slight (and optional) modification to al-Marrākushī's device by folding the markings that fall outside of the quadrant *MHN* over the inner surface of the quadrant, by reflection about its vertical side *HN* (see Fig. 5.12). Since the marking of radii greater than 60 with the thread is no more possible, the concentric arcs on the folded portion are now represented for each unit of radius.

Presumably because of the resemblance of the declination lines with those of the horary quadrant of Ch. 69 (or vice versa), which is called "horary quadrant with the harp" (*sāʿāt al-junk*),[26] Najm al-Dīn called this instrument the *mujannak* quadrant, which can be best translated as "quadrant with (markings reminiscent of) a harp".

[26] See pp. 129–130 above.

5.4 *The* shakkāzī *quadrant as a trigonometric grid*

A remark on the *shakkāzī* quadrant is appropriate. In Chapter 2 it was observed that instruments based on a universal stereographic projection operated conversions from one celestial coordinate system into another, by virtue of the properties of stereographic projection and the spherical configuration of the celestial sphere. The *shakkāziyya* was eventually restricted to a quadrant and lost the markings corresponding to the projection of the ecliptic coordinate system. The result is the *shakkāzī* quadrant,[27] which is identical to a particular kind of 'meteoroscope' designed by the early sixteenth-century German mathematician and astronomer Johannes Werner and illustrated by Peter Apian in his magnificient *Astronomicum Caesareum*.[28] Historians of mathematics have stressed that the *use* of the meteoroscope as an abstract graphical device for solving spherical triangles represents a new and original chapter in the history of trigonometry.

> In summary, Werner and Apian had shown how, equipped with a meteoroscope of the saphea kind, a person without mathematical knowledge could solve any spherical triangle.[29]

What until now has remained virtually unknown, however, is that the *shakkāzī* quadrant was *also* used by Mamluk astronomers as an abstract grid in a way not unlike that of Werner and Apian, and Mamluk authors even consciously classified this quadrant among the *trigonometric* instruments.[30] Unpublished treatises by Ibn al-Sarrāj, Ibn al-Shāṭir and many others demonstrate this tradition, which I treat fully in a separate study currently in preparation.[31]

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[27] Several authors also name it after the nature of its markings as the *muqanṭarāt khaṭṭ al-istiwāʾ*, "altitude circles at the equator".

[28] See North 1966-67.

[29] *Ibid.*, p. 64.

[30] See for example Ibn al-Sarrāj, MS Princeton Yahuda 296, ff. 8v-10v and Ibn al-ʿAṭṭār, *Kashf al-qināʿ*, MS Vatican Borg. 105, f. 5v:6-15 [*qism* 2, *faṣl* 2].

[31] Listed in the bibliography as King & Charette, *Universal Astrolabe*. See already the insightful remarks in Samsó 1971.

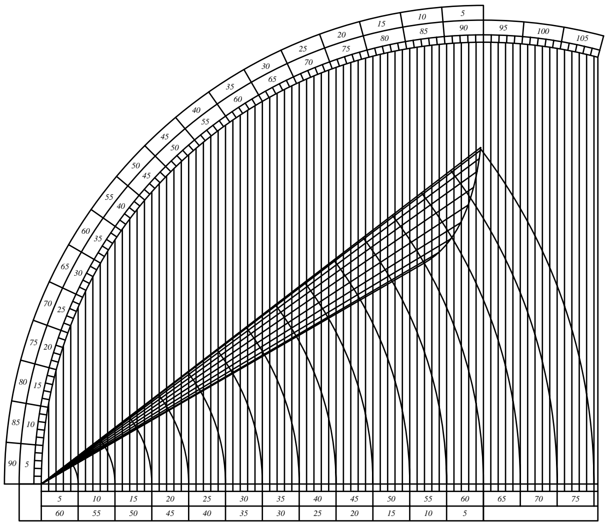

FIG. 5.11. al-Marrākushī's "figure for finding the hour-angle"

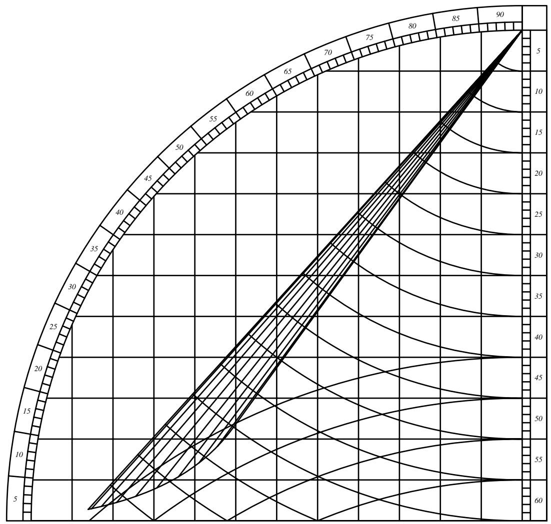

FIG. 5.12. Najm al-Dīn's *mujannak* quadrant

CHAPTER SIX

MISCELLANEOUS INSTRUMENTS

6.1 *Observational instruments*

In a treatise concerned almost exclusively with nomographic instruments, Najm al-Dīn thought it appropriate to describe the construction of three purely observational instruments: the armillary sphere, the parallactic rulers (in Arabic "[instrument] with the two rulers") and a third one called simply the "ruler", which is a simplification of the second. His descriptions merit little comment, as they are incomplete and hardly intelligible.

The armillary sphere (*al-aṣṭurlāb al-raṣadī*, or *dhāt al-ḥalaq*),[1] is only unwillingly presented in Ch. 30, as the author himself confesses; even the reason given for including it, namely, that it is "a basic (form) to all (instruments)", is quite puzzling. Nevertheless, Najm al-Dīn would have been better advised to omit it altogether, for he does not describe it at all, apart mentioning that it has seven rings, although some people say it should have nine. His foolish instructions on the geometrical construction of a ring deserve no comment. More interesting is the reference in the title and the caption of the illustration to the alternative appellation of the armillary sphere as an "observational astrolabe", which is clearly related to Ptolemy's terminology (*Almagest*, V.1), where this instrument is called an *astrolábon orgánon*.[2]

As for the parallactic rulers (*dhāt al-shuʿbatayn*) (Ch. 59), the text, unclear enough in itself, has been rendered yet more obscure by a completely erroneous diagram. What is intended is an instrument like Prolemy's, slightly modified in order to measure the altitude through sines instead of chords: a thread is attached at the lower extremity of the movable ruler, and the position of the plumb-line on a cosine scale (with base 60, the length of the rulers and of the vertical mast being likewise 60) will readily yield the altitude. This notwithstanding, the text also refers to a chord-scale, so that the cosine scale on the ground may have been intended as an additional feature to the standard Ptolemaic instrument, which would retain its second ruler fixed at the base of the mast. The illustrations in both copies show the thread attached to the junction of the vertical and movable segments, which is absurd.

[1] On this instrument, see Nolte 1922 and Celentano 1982.
[2] Ptolemy, *Syntaxis Mathematica*, p. 350.

What appears to be intended as a simplification of this instrument is presented in Ch. 105. Yet Najm al-Dīn's description of it is hopelessly sibylline. A ruler divided into 60 equal parts on its face and into 30 more (equal?) parts on its back – said to correspond to 25 of the parts on the face (?) – is (presumably) provided with sights. A thread is attached to it and, as on the previous instrument, is to fall on a scale at the time of observation, to indicate the altitude.

6.2 *The Fazārī balance*

The name of this multi-purpose instrument is possibly related to the eighth-century astrologer and astronomer al-Fazārī, who might be its inventor. It consists of a wooden parallelepiped with four identical rectangular faces and square extremities; each of its four rectangular surfaces bears different markings, either sundials, graphs or tabular data. We have already described the various sundials associated with this "balance".[3] As far as I am aware, the first extant description of this instrument is by al-Marrākushī, who described its construction and also explained its use in 50 chapters.[4] There is an anonymous treatise on the "Fazārī balance" attributable to Naṣīr al-Dīn ibn Samʿūn, a contemporary of Najm al-Dīn, and which deserves investigation.[5] Najm al-Dīn's description of this instrument in Ch. 95 is incomplete and incompetent.

6.3 *The* bādahanj

The device featured in Ch. 91 is not, properly speaking, a scientific instrument. It is one of the most curious features of Najm al-Dīn's treatise. In this chapter, a method for properly aligning a *bādahanj* (i.e., a ventilator or "wind-catcher") in the city of Cairo is described, which is directly related to folk astronomical and meteorological traditions. This text has been edited, translated and analysed by David King in a study on the ventilators of medieval Cairo.[6] A particularly interesting aspect of this chapter is that it pertains to the 'folk astronomical' tradition, while integrating methods from mathematical astronomy (cf. Section 1.4.1).

[3] See pp. 147 and 163.

[4] al-Marrākushī, *Jāmiʿ*, I, pp. 251:6–254:1 [part of *fann* 2, *qism* 2, *faṣl* 9]; Sédillot, *Traité*, pp. 465–469.

[5] It is preserved in MS Cairo QM 2/5, ff. 92r–98r.

[6] King 1984, pp. 109–111 and 128–129.

6.4 *The* mubakkash

This instrument (Ch. 32), which at first sight makes as mysterious an impression as does its curious name, serves as a graphical device (i.e., a nomogram) for converting between equal and seasonal hours. It is absolutely unique in the medieval literature, being featured neither in manuscripts nor on extant instruments. The word *mubakkash* (or *mubakkish*) escapes explanation: even its root *b-k-sh* is not found in classical Arabic dictionaries. In Egyptian Arabic, the verb *bakkish* means "to fool, bluff, act fraudulently".[7] Could the *mibakkish* or *mibakkash* instrument be intended to defraud? I think the meaning is in fact semantically related to the term *ḥīla* (pl. *ḥiyal*) (trick, artifice), which designates "ingenious mechanical devices" in classical scientific Arabic.[8] The *mubakkash* was then probably intended as a wondrous (mathematical) device, the result of an ingenious 'trick'. The text, however, gives solely the construction procedure; there is not a hint of the way the instrument is to be used.

Construction. First, the basic elements of a northern astrolabic plate are traced: two perpendicular diameters NS, EW and the circles of Cancer, equator and Capricorn (see Fig. 6.1). Then two marks X and Y are made on each tropic in such a way that the lines OX and OY define an angle of 30° with respect to the horizontal diameter EW. Then a circular arc XY is traced, which also passes through the intersection of the equator with radius OS. Arc XY is divided into 60 parts on each side of the meridian OS, so that each of its divisions x_i defines an angle $\angle SOx_i = i$, with $i = 6, 12, \ldots, 60$: this scale is labelled "arcs of the (positive or negative) excesses".[9] These divisions in turn define the radii Ox_i of a series of concentric arcs, traced from line ON to arc XY, the length of each arc being within the range 120°–240°; the length of each arc represents the duration of daylight for a particular solar longitude. The tropics and the equator are then divided into 180 equal parts (in fact 30 parts, since they are marked with 6-unit increments on the diagram). For each division of the daylight arcs, the three points hence defined are joined through a circular arc. The latter are labelled along arc XY $6, 12, \ldots, 90$, beginning from line ON, in both directions. Najm al-Dīn's *mubakkash* also features a trigonometric quadrant (with vertical lines for the cosines and corresponding

[7] See Badawi & Hinds, *sub* "*b-k-sh*". In the Maghribi dialect, however, the word *bukkūsh* is attested as meaning "dumb": see Dozy, *Supplément*, s.v. A link with the Persian word پکشه ("swelling, tubercle") seems very unlikely.

[8] The two most important Arabic treatises on mechanics, by the Banū Mūsā and al-Jazarī, have indeed the word *ḥiyal* in their titles; see Hill 1974 and idem 1979.

[9] The text has "arcs of the excesses (whose signs) is the same as the sign of the latitude" for the positive ones, and "arcs of the excesses (whose signs) differ from the sign of the latitude". But this formulation implicitly assumes a terrestrial latitude in the northern hemisphere.

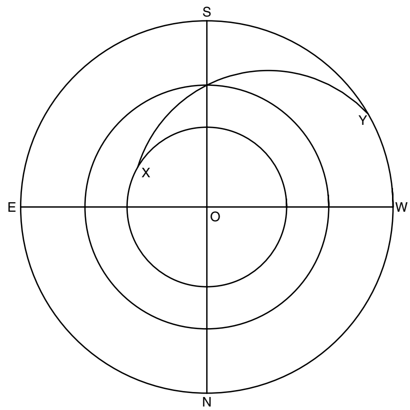

FIG. 6.1. Construction of the *mubakkash*

concentric arcs) in the lower left quadrant. The resulting instrument is depicted in Fig. 6.2: see also the illustration in manuscript **P** reproduced on Plate 16.

Use. The *mubakkash* presumably achieves the conversion

$$\tau' \to \begin{cases} T & \text{before noon,} \\ 180^\circ - T & \text{after noon,} \end{cases}$$

where T is the equatorial time since sunrise, and τ' is the 'seasonal time' since sunrise, 15 times τ, the time since sunrise in seasonal hours (recall the definition of τ as $6T/D$). In the text of Ch. 32, the *mubakkash* has a thread attached at the centre. To use the instrument, determine τ' (or $180^\circ - \tau'$ if it is larger than 90°) as well as the value of the maximal half-excess for a given latitude. Put the thread at the intersection of the appropriate concentric circle with the curve corresponding to τ': the angle made between the thread and the radius ON will yield the time since sunrise T. The converse operation is obvious.

On the illustration accompanying Ch. 32 the scales on the outer rim of all four quadrants are numbered 0–90, starting from the east and west points. It would have been a wiser choice to label the three quadrants of the *mubakkash* continuously from 0 to 270, starting at N, in order to directly enter T on the scale.[10] It is likewise odd that on the illustration the arcs of τ' are numbered at each 6°: a choice of 5° intervals would indeed correspond to one-third

[10] Alternatively one could have added an hour scale, one equal hour at each 15°.

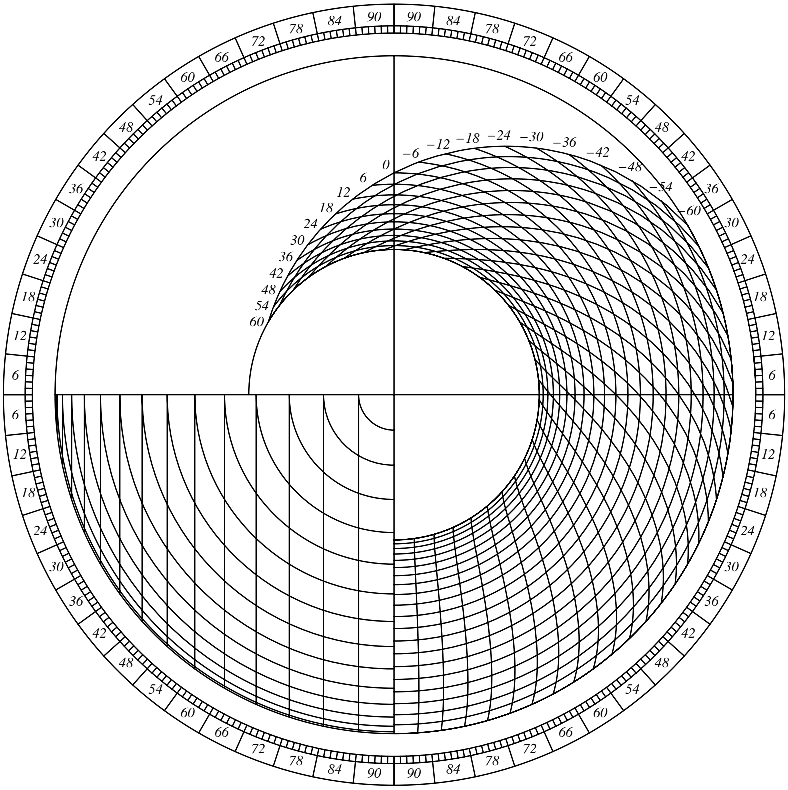

FIG. 6.2. The *mubakkash* device

of a seasonal hour and would then facilitate converting hours, which here is achieved only in a rather awkward manner.

A note at the bottom of the illustration claims that the instrument is universal and works for all solar longitudes up to a terrestrial latitude of 60°, and thereafter (up to 89°) only for a restricted part of the ecliptic. Two problems arise. First, for ‘60’ one should read ‘66[;25°]’, the complement of the obliquity, since up to that latitude the length of daylight is smaller or equal to 360°. Second, the scale for the excess of daylight is limited to a maximum of 60°, which corresponds to the maximal daylight for latitude 48°, roughly equal to the upper limit of the seventh climate, which is the ‘limit of universality’ adopted by the author. For latitudes higher than 48°, the scale of excesses should be extended to ±90°, but then the concentric arcs would crowd very close to each other.

Mathematical analysis. Circular arc XY is defined in such a way that it is equivalent to a section of the horizon on an astrolabic plate for some latitude ϕ^* whose maximum excess of daylight is 60°. (Here this astrolabic plate would be seen sideways, with the south coinciding with the west point of the *mubakkash*.) From the formula for the half excess of daylight this latitude is

$$\phi^* = \arctan\left(\frac{\sin 60^\circ}{\tan\varepsilon}\right) \approx 63.25^\circ .$$

The centre of this 'horizon' is located on radius OW at a distance a from the centre O, its radius being r; these quantities can be expressed as

$$a = \frac{R_E}{2}\left(\cot\frac{\phi^*}{2} - \tan\frac{\phi^*}{2}\right) \qquad \text{and} \qquad r = \frac{R_E}{2}\left(\cot\frac{\phi^*}{2} + \tan\frac{\phi^*}{2}\right),$$

where R_E is the radius of the equatorial circle. If $R_E = 60$, then $a = 30.25$ and $r = 67.19$. The divisions on arc XY define the radii of a family of concentric arcs, which can be expressed in terms of the half-excess of daylight d by the formula:

$$\rho(d) = \sqrt{r^2 - a^2 + a^2\sin^2(2d)} - a\sin(2d).$$

The second family of curves represents the 'seasonal time' τ' as a function of the excess of daylight $2d$. The instructions suggest drawing these curves as circular arcs through three points marked on the 'tropics' and the 'equator'. This procedure only approximates the exact curves, whose equations can be expressed in polar coordinates as

$$\rho = \sqrt{r^2 - a^2 + a^2\sin^2\gamma} - a\sin\gamma \qquad \text{with} \quad \gamma = 180^\circ\left(\frac{\beta}{\tau'} - 1\right),$$

where β is the polar angle measured from line ON, and with

$$\beta_{\min} = \tfrac{2}{3}\,\tau' \quad \text{and} \quad \beta_{\max} = \tfrac{4}{3}\,\tau' .$$[11]

[11] When $\tau' = 180^\circ$ (i.e., at sunset), the above becomes the polar equation of a circle of radius r centred at (a, 0). When $\tau = \frac{180^\circ}{n}$ ($n \geq 2$), the equation, whose basic form can be expressed as $\rho^2 - 2\rho\,\sin(n\theta) - c^2 = 0$, defines very nice curves of order ≥ 4, resembling sea-stars with n branches.

Part III

TRANSLATION OF NAJM AL-DĪN AL-MIṢRĪ’S TREATISE ON INSTRUMENTS

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[Last chapter of the first part on the use of Najm al-Dīn's auxiliary tables and conclusion thereof][12]

Chapter 130. On finding the radii of the altitude circles and parallel circles (on the astrolabe).

When you want the smallest distance from the 'pole',[1] take the difference *p. 51* between the altitude argument and the terrestrial latitude. Take the tangent[2] of half of it, and keep it in mind. And if you want the largest distance, add both (quantities), take half of the sum, and keep it in mind. Then take its cotangent from the shadow table. Add to each of the two memorised (quantities) two thirds of them. Subtract from this sum, for each degree, one second of arc. What remains is the desired radius (of the altitude circle). If the sum is greater than ninety, subtract it from hundred and eighty. Take the tangent of half of the difference and add two thirds of it, as you first did. If you want to place it in a tabular form, then you will be able to construct the altitude circles with it, provided that the radius of the plate has thirty (parts). That is for the northern region.[3] On the southern one, the procedure is the reverse (of what has previously been described).

If you want the prime vertical, add the terrestrial latitude[4] to ninety, take the tangent of half of the sum, and keep it in mind. Then subtract the terrestrial latitude from ninety, take the tangent of half of the difference, and keep it in mind. Add to each of the two memorised (quantities) two thirds of them. Subtract from (each of) the (two) sums, for each degree, one minute (of arc). What remains are the farthest and nearest distances[5] (of the prime vertical). Add them together and take half of the sum: this is the distance of the centre of the circle of the prime vertical from the 'pole'.

< Another method: > If you wish, add together the cotangent and the tangent of half the (meridian) altitude at equinox (*niṣf irtifāʿ al-ḥamal*). Add to this sum its two thirds and subtract one second (of arc) for each degree < thereof >. The result is the distance of the centre of the (projected) circle of first azimuth. God knows best.[6]

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12 On Part 1 of the Dublin manuscript see pp. 27*ff.* of the introduction.

1 I.e., from the centre of the astrolabic plate, which coincides with the projection of the northern/southern celestial pole on a northern/southern astrolabe.

2 In the translation, the terms tangent and cotangent will always refer to the trigonometric function Tan and Cot to base twelve, and sine and cosine to the functions Sin and Cos to base sixty.

3 I.e., the projection of the northern hemisphere.

4 The text has 'complement of the terrestrial latitude'.

5 The text has 'radii'.

6 This second method is equally wrong!

<Conclusion of Part 1>

The *Shaykh* – may God be pleased with him – said: The chapters on the operations (with the tables) are finished, with the help of God full of Majesty (*dhū l-jalāl*). We have composed 130 chapters, among which 127 do not refer to (the operations of) multiplication, division, square root extraction or proportions. All of them can be artfully (resolved) with the tables, and three chapters require (the use of) multiplication, division and proportions. I did not place (these arithmetical operations) in the chapters, except when they are indispensable (*illā li-kawn allā ghanāʾ ʿanhā*). Most of their determination (i.e., of the solutions to the operations of spherical astronomy) are artfully achieved by means of the tables and by two (other) methods (*bāb*), the first one being (exemplified) in Chapter 119, and the other one <in> Chapter 120. The third method is in Chapter 128. I only mentioned them in this book of mine because they are (really) needed. I composed (the chapters on the operations) without consideration of their methods (*abwāb*). I do not know anybody who has mentioned them in these times of ours, and for this reason I mentioned them in my book.

I indeed turned myself to the already mentioned (operations of) multiplication, division and proportions; and whoever understands them will like to forbear us for having mentioned them according to the method of multiplication, division and proportions, because these operations are the common ones. God shows the path to the Truth.

There follows the table of declinations and equations,[1] God Almighty willing. God is sufficient for us! And how sublime a Guardian is He![2]

<Interlude on the tables of proportions>

In the name of God, Merciful and Compassionate

The learned and venerable *Shaykh*, author of this book – may God be pleased with him and may the Muslims benefit from that which he has left (them in this book ?) – said: We need to present the evidence about the correctness of the operations by the way of calculation that was mentioned to the eminent men amongst the people of this science. I have chosen (to do) this in the easiest way and the most straightforward approach of tabulation, attributed to the eminent *Shaykh* Abū ʿAlī al-Marrākushī – may God have mercy upon him. It is the table known as the 'Table[1] of Proportions', which consists of 62 operations along the length of the table and four entries along the width of the table.[2] He has mentioned that each entry is in one of the four cells (*bayt*).

[1] This table is found in **D**:24v. See Appendix A.

[2] *al-Qurʾān* III, 167.

[1] 'Tables' in the text.

[2] al-Marrākushī's 'Table of Proportions' consists indeed of 62 entries. See al-Marrākushī, facsim., pp. 180–182 and Sédillot, *Traité*, pp. 351–359.

The use thereof: Multiply one of the extreme (horizontal entries) with the other one. Divide the resulting product by one of the intermediate ones. There results one of the intermediate (entries). Or multiply one of the intermediate (entries) with the other one. Divide the resulting product by one of the extreme ones: there will result one of the extreme (entries).

Explanation of this: Multiply the first (horizontal entry) with the fourth one and divide it by the third one, and there results the second one. Or divide it by the second one, and there results the third one. Or multiply the second (entry) with the third one and if you divide the resulting product by the first one, there results the fourth one; and if you divide it by the fourth one, there results the first one. I have taken fifteen operations from those attributed to the *Shaykh* Abū ʿAlī, and I have completed them with fifteen (more) operations, which makes up thirty operations, for establishing the proof of the exactness of the operations mentioned (in the treatise), which are (in) hundred and twenty-five chapters. With these thirty it is possible to determine 92[3] problems (*bāb*). There remains thirty-five that need nothing (?). This is clearly explained from their chapters. God knows best that which is obsure $<$ and $>$ (He is) most wise. It is this table which is on the back of this sheet.[4] May God bless our Prophet Muḥammad, his family and companions, and may He grant them salvation.

[3] Read 90?

[4] These tables are reproduced with modern mathematical symbolism in Appendix B.

[Part 2 – On Instrumentation]

<Introduction>

The learned and venerable master, most excellent and distinguished (among the men) of his time and author of this book – may God be pleased with him – said: Whoever wants to determine one of the operations (described in the book) can find it from its (appropriate) chapter, and do what we have mentioned. If he wants to check it (*tastamḥanahu*), its operation (may be taken) from the list of proportional relations tabulated on the back of this page. But if you do not find it there, be aware that it is clearly explained in its chapter (and that) no multiplication, division, square root or ratio are needed. Know (also) that all the yield (*thamara*) of this art that you are seeking is found in (this book) except the basic principles of a few chapters. And (these principles) are not found (in the commentary), because if an orphan (*al-*…[1] *al-yatīm*) would come, all doors would be open (i.e., all methods would be known).[2] (Furthermore) no auxiliary quantities (*al-muwaṣṣil*) are required for that (purpose), like the 'argument of the azimuth' (*ḥiṣṣat al-samt*), the 'directed sine' (*jayb al-tartīb*), the 'hypothenuse' (*quṭr*) or anything like that. The azimuth may be found from the altitude without (using) the 'argument (of the azimuth)', and the time-arc may be found from the altitude without (using) the 'directed sine'. As for (determining) the altitude from the shadow, one cannot save himself from the use of the hypothenuse, because the hypothenuse is the basic (quantity for finding) the altitude (from the shadow). (But) whenever we can determine the altitude from the shadow without (using) the hypothenuse, then its hypothenuse is no more needed. For what is the purpose of all things, if not the benefit they can yield? May God who helps be praised.

We have compiled two (sets of) tables: the first of these is for the construction of the altitude circles and azimuth circles for all instruments involving these. As we desire that they be (made) at each six or three (degree of interval) or otherwise, we have determined the time-arc for the altitude argument according to Chapter 21, and we have subtracted it from the half arc of daylight, thus obtaining the hour-angle. We have placed it (in the table) vis-à-vis the corresponding argument of the altitude circle, for the desired latitude, and for the two solstices. When the meridian altitude is attained, we determined it for the equinox, and whenever the meridian altitude is again attained, we determined it for Taurus, Gemini or for a star whose declination is equal to the latitude of the location.

For the azimuth circles, when you want that they be (made) at each ten or five (degree of interval) or otherwise, determine the altitude corresponding to the azimuth argument according to Chapter 25, for the solstice whose

[1] *Illegible word*

[2] This seems to be a proverbial pun.

TABLE T.1. For constructing altitude <and azimuth> circles for latitude 36°

h	Cancer	h	Aries	h	Capric.	
0	108;21	0	90;00	0	71;39	
6	100;20!	6	82;36	6	62;50	
12	92;00	12	75;07	12	52;47!	
18	84;10	18	67;35	18	42;51	
24	76;34	24	59;49	24	30;00	
30	69;08	30	51;51	30	7;20	
36	61;36	36	43;26	—	—	
42	54;05	42	34;15			
48	46;38	48	23;16		Aries	
54	39;08	54	0;00	az	h	T
			Taurus	10	13;36	16;53
60	31;36	60	18;36	20	25;21	31;58
			Gemini	30	34;35	44;34
66	23;50	66	21;34	40	41;31	55;00
72	14;57	72	11;23	50	46;28	63;39
	$\Delta = 36$		$\Delta = 30$	60	50;08	71;37
78	14;50	78	12;22	70	52;14	77;51
84	7;26	84	0;00	80	53;26	84;00
90	—	90	—	90	54;00	90;00

direction is opposite to that of the terrestrial latitude, running from the rising amplitude to 90 degrees. What is smaller than the rising amplitude, determine it for the equinox, and place it (in the table) vis-à-vis the azimuth argument. We determined the time-arc from the altitude and the azimuth and we have likewise place it (in the table) vis-à-vis the azimuth argument. This is what is required for the construction of the lines of azimuth. If you want, you may determine the altitude for those azimuths at the equinoxes as we (just) mentioned, or you may (also) enter the (table of) half excesses with the azimuth for the desired latitude. Take the declination you find: this will be the altitude for that azimuth, specifically at the equinoxes. A time-arc is obtained for it according to its (appropriate) chapter; place it in the table, which is the one we have compiled.

For the day-circles, determine the meridian altitude for that degree according to Chapter 4. Understand it. For the division of the ecliptic, determine the (right) ascension of all signs of the zodiac from the table of right ascension and keep it in mind for the time (when it will be) required.

The other (set of) table(s) is for the construction of the hour-lines of horizontal, vertical, inclined, conical, hemispherical, cylindrical and other sun-

dials involved with horizontal or vertical shadows, or with auxiliary ones (*mustaʿmal*) or with shadows that are inclined with respect to the surface of the sundial or otherwise. We have determined the (horizontal and vertical) shadow(s) for each hour and its azimuth, from its altitude, according to the (appropriate) chapters mentioned before. We have placed it (in the table) under each sign of both solstices for the latitude we desired: this is the sundial table (*jadwal al-basīṭa*).[3]

As we want both the seasonal and equal hours, we have disposed them in two tables, (one) for the seasonal (hours) and (the other) for the equal ones. Since we want to mark the time-arc (on some sundials), we have (also) compiled for it a table (designed) in terms of the time-arc at each three (degrees) for latitude 36°. We determined the altitude (corresponding to) that time-arc according to its chapter, and we have placed it in the table. Then we have found the horizontal and vertical shadows and the azimuth corresponding to that altitude, (each operation) according to its (appropriate) chapter, and we have (likewise) place it in the table for the time (when it will be) required. Since we (also) want (to construct) the altitude (markings) on the horizontal sundial, it is required to compile for it a table in terms of the altitude at each five or six (degrees). We find the horizontal and vertical shadow of that altitude from the (appropriate) chapters (*min bābihimā*) and we have written the two (in a table) for the time (when it will be) required. Praise be to God the Only One.

1 *On the construction of the altitude circles of northern astrolabes.*

pp. 49, 52, 58 (The construction) is indeed related to the construction of the ecliptic of the rete. If Capricorn is the largest of the circles of the rete, the (astrolabe) is northerly, and if it is the smallest one, then it is southerly.

Trace a circle and divide (its circumference) into 360 equal parts. Divide it (also) into four quadrants (defining four radii that) you divide into 30 parts. From this quantity take $19;39^p$ and trace a circle with this opening (of the compass): this will be the circle of Aries (i.e., the equator). Take from this opening (a quantity of) $12;54^p$ and trace a circle: this will be the circle of Cancer. Then take $15;30^p$ for Taurus; $13;42^p$ for Gemini and trace both circles and have them ready (to be drawn) at the time required. Take $10;2^p$ for the zenith. For the star whose declination is 30°, take $8;46^p$ (as a distance) to the nearest 'pole', and $11;46^p$ to the farthest one.[1] Both of them are on the meridian line on the northern surface (of projection), when the first (circle) is the circle of Capricorn, and inversely on the southern surface (of projection). As we want to present the explanation of the way how we can achieve this

[3] Tables for constructing sundials are found on ff. 46v–47r. See the commentary on p. 187.

[1] The latter sentence makes no sense, and the two given values are apparently corrupt.

with the help of the tables mentioned, which are labelled ‘finding the radii of the day-circles and of the altitude circles’, we can determine it according to the procedure (*faṣl*) mentioned in the last of the chapters[2] and we can place it in a tabular form. If we want to perform the construction with it, there is no need for any other table. (But) if we want to do what we have mentioned previously,[3] (then let us consider the following operations.)

If you want the altitude circles,[4] place the ruler on each of these day-circles: the circle of Aries, the circle of Cancer and the circle of Capricorn, for which the hour-angle has been calculated (and place the appropriate marks on their intersection). When the meridian altitude of Aries is reached (as an argument of the table), the altitude circles are completed for Taurus, and when the meridian altitude of Taurus is reached, they are completed for Gemini, and when the meridian altitude of Gemini is reached, (they are completed) for the two stars mentioned. (This is done) until you reach the zenith.

If you want the azimuths, take the time-arc vis-à-vis the azimuth (in the table) and do as you did already for the altitude circles, except that you start from the east-west line (instead of the meridian line). Mark off the intersections of the ruler with the circle of Aries and retain them (for later use). Place one leg of the compass on the ‘pivot line’ [5] and go forwards or backwards until you can join together the two ‘poles of projection’[6] and the zenith (with a circular arc). With the other leg trace a circle, which will be the circle of the prime vertical. This was the geometrical method. If you wish (to find the prime vertical) by the tabular method, determine it in accordance with the procedure (*faṣl*) mentioned in the last of the chapters (of Part 1). Once you have drawn the circle of the prime vertical trace a line (going through) its centre (i.e., of the prime vertical), parallel to the ‘line of the poles’,[7] to the left and to the right: (this line) is called ‘the east-west line of the prime vertical’. Place one leg of the compass on that line and the other leg on the point of the zenith, and on each mark made on the circle of Aries for this (purpose of constructing the azimuth circles), until it fits (?).[8] Trace a circular arc from the largest day-circle to the horizon, at the left, and likewise from the largest circle (to the horizon), at the right. (Do this) until you have completed the azimuths.

If you want the hours, place the ruler on the parts of the hours corresponding to that day-circle and on the centre of the circle.[9] Make a mark on each of the three day-circles and join them by successive approximations. (Do it)

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[2] That is, Chapter 130 of Part 1.
[3] That is, constructing the altitude circles as mentioned in the title of this Chapter.
[4] The text has erroneously: ‘If you want these three day-circles’
[5] I.e., the lower half of the vertical diameter. Cf. p. 49 of the commentary.
[6] I.e., the east and west points. Cf. p. 49 of the commentary.
[7] The line going through the two poles of projection is here meant, i.e. the east-west line!
[8] The text has rather ‘if it fits’ (? *in ittafaqā*).
[9] I.e., the centre of the plate.

until the twelve seasonal or equal hours are completed.

If you want the depression circles,[10] place (the ruler) on the mentioned day-circle, according to the table on the back of this page, for that sign of the ecliptic, and do as you did previously.[11] When you place them it is necessary that you (also) complete the azimuths above the altitude circles and underneath them.[12] You have thus completed the construction of the astrolabic plate (*al-safīḥa*).

If you want to make the rete, open (the compass) to the radius of the greatest circle (of the plate). Trace a circle and divide it into four quadrants. (Open the compass) to the quantity between the largest and smallest circles, above the altitude circles (i.e., above the horizon ?) and underneath them.[13] Place one leg of the compass at the intersection of the largest circle with (one of the) diameters and make a mark with the other leg on the line mentioned. Hold the compass fixed and trace a circle, which will be the circle of the ecliptic.[14] Trace beneath (i.e., within) this circle three (other) circles, and write on the first of these[15] the names of the signs of the ecliptic, and on the other one their degrees. Once you have done that, place the ruler on the right ascensions of that sign (on the graduated scale of the rim), taken from a table, and on the centre of the rete. Trace a line passing through these three circles, (and repeat this operation) until all signs of the ecliptic are completed.

If you want (to make the pointer of) a star, place the ruler on its mediation and at the centre of the rete and trace a line connected to the centre. Then place one leg of the compass on the centre of the plate and the other leg on the altitude circle of its meridian altitude, and move the compass so that you place one leg on the centre of the rete and the other leg where it falls on that line (previously drawn). This will be the location of the star-pointer. Attach it (*fa-shbikhu*) to the nearest location on the rete, and engrave its name on it. If there are negative altitude circles on (the plate) and if the greatest circle is that of Capricorn, then write on the star (-pointers) that are south of Capricorn the letter جـ, and if is it the smallest one, then write ش, in order to recognise by that its direction, since we have drawn the depression circles because of these stars with these letters written on them. Then <make> the degree pointer (*murī al-ajzā*ʾ) at the beginning of the zodiacal sign that is nearest to the limb. If you want to construct of the hours by geometry, divide each

[10] I.e., the circles of negative altitude, underneath the horizon.

[11] Actually, the opposite sign should be used, since negative altitude circles in northern projection are identical to positive ones in southern projection.

[12] I.e., above and underneath the horizon.

[13] The intended meaning seems to be: the distance from the top of the largest circle to the bottom of the smallest one.

[14] The text is unclear: the two marks actually represent the two extremities of the vertical diameter of the ecliptic, so that the fixed compass has to be hold at the midpoint between them.

[15] Actually, in the space between the first and the second.

circle of declination in twelve (equal) parts and join them with a circular arc. You have thus constructed them.

{*Diagram*}[16]

Diagram of the northern astrolabe for latitude 36°.

<Text in the diagram:> Latitude 36°. – Hours: 14;30.[17]

{*Diagram*}[18]

Northern rete, Capricorn being the largest circle.

<Text in the diagram:> (Zodiacal signs) – (star names)[19]

2 *On the construction of the depression circles, namely, the altitude circles of the southern astrolabe, on their own.*

This is related to constructing the ecliptic of the rete: If Capricorn is the largest of the circles on the rete, it is southerly and if it is the smallest, it is northerly. If you want that, do what we have mentioned in the first chapter on the construction (of the northern astrolabe) and take (the entries needed) from the table for (constructing) the depression circles and make it according to what has been mentioned: the result will be what you want. *p. 57*

{*Diagram*}

Diagram of the southern astrolabe[1]

<Text in the diagram:> Latitude 36°. – Hours: 14;30. – East, West. – First, second, . . . , twelfth (hour).

3 *On the construction of the quadrants that are related to the astrolabes mentioned.*

Trace a circle and divide it into four quadrants. Open (the compass) to the hour-angle (*tafāḍil al-dāʾir* !), which is written down in the table with which you constructed the altitude circles. Place one leg of the compass on the meridian line intersecting the larger circle and with the other leg mark off *p. 84*

[16] See Plate 1.

[17] The obliquity underlying this value of the maximal daylight is within the interval (23;48,23;56), so that the most probable underlying obliquity is Ptolemy's (truncated) value of 23;51°. With Najm al-Dīn's maximal daylight of 108;21° [error $-9'$], one would obtain 14;27 hours. See also the next Chapter.

[18] See Plate 1.

[19] The names of the stars featured on the retes are included in the edition of the Arabic text. They are also listed, chapter by chapter, in Appendix C.2, with reference to Najm al-Dīn's star table.

[1] On **D**:99v, there is also the incomplete illustration of a southern plate (drawn upside-down).

(that amount) on that circle. Repeat that (operation) until you have used all entries of the hour-angle (in the table) and do it for each of the three day-circles. Join (each set of three marks) to form circular arcs: these will be the altitude circles.

Then open (the compass) to the distance of the prime vertical opposite (the argument) in the azimuth table. Place one leg of the compass on the pole of projection and the other leg where it meets the 'pivot line'. Trace it as a straight line: this will be the eastern line of the prime vertical. Join (the marks for the azimuths) to the zenith point as you did previously.

{*Diagram*}

Diagram of the quadrants for latitude 36° north.

<Text in the diagram:> The southern quadrant. – Horizon for latitude 36° north. – The northern quadrant. – Horizon for latitude 36° north. – The excess is 18;30°.[1]

4 *On the construction of the quadrant called 'the candied sugar' (*al-sukkar al-munabbat*) (also) known as the (quadrant) marked with azimuths (*al-musammat*).*

p. 137 If you want that, trace a circular arc and make a quadrant out of it, which you (further) divide into 90 (equal) parts. Divide the eastern line in 90 equal parts, beginning from the centre. Place one leg of the compass at the centre and the other leg on (the quantity corresponding to) the meridian altitude (for a particular solar declination) and trace a circular arc from the east line to the meridian line. (Repeat this operation for all signs of the ecliptic) until you have completed the day-circles. Write on each of the day-circles the names of the (corresponding) signs of the ecliptic at the right and at the left. Place one leg of the compass at the centre and the other leg upon the first argument of the outer scale.[1] Hold it there and trace (*iḍrib*), with the compass lying at the centre, a circular arc from the day-circle of Capricorn to the day-circle of Cancer. There results (?) the arc of the horizon. Place one leg of the compass on the beginning of the arc (of the quadrant) and the other leg upon the altitude argument corresponding to the time-arc (*dāʾir*) for the three day-circles that are in the table. If you want it for each five or each three (degrees) or otherwise, make a mark with the compass on the three day-circles. When you have marked these three day-circles, these will be the marks of the arcs of the time-arc. In case one of the solstices is completed,[2] join (the marks of) the other solstice and of the equinox, and if the equator is completed, determine

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[1] This is the correct value of the half-excess of daylight for an obliquity of 23;35°. Cf. p. 237, n. 17.

[1] Literally 'the first division of the arc of the quadrant'.

[2] I.e., when all entries in the table have been used.

(the time-arc) for the point of the ecliptic that is in-between. Continue to do this until the arcs of the time-arc have been completed.

If you want the azimuth at the solstices, determine the altitude corresponding to this azimuth for the two points of the ecliptic mentioned (the solstices) and do as you did for the time-arc. Know that the table (of the azimuth) for Aries has been placed in the table already mentioned. If you have made marks on the three day-circles, then join them with arcs of circle: these will be the arcs of the azimuth. In case one of the solstices is complete, join (the marks of) the other solstice and of the equinox, and if the equinox is complete, determine (the azimuth) for the point of the ecliptic that is in-between. Continue to do this until the arcs of the azimuth have been completed.

I have constructed this quadrant of my invention (lit., 'this invented quadrant') in order to supersede the astrolabic quadrant, which has already been mentioned. We have deliberately (shown) in a treatise (on its use) that all that can be known from the common astrolabic quadrant can (also) be known from it, be it (provided) with a thread or with an alidade. We entitled it *The candied sugar on the use of the azimuthal quadrant*.[3] The number of its chapters is one hundred, and this is sufficient, for otherwise its reader would have been bored, had we composed it with, say, five hundred (chapters). God is sufficient for us! And how sublime a Guardian is He![4]

These two quadrants were made by the *Shaykh* Muḥammad ibn al-Sāʾiḥ[5] out of a quadrant of brass. The first face was fitted with an alidade on which altitude arguments (*muqanṭarāt al-irtifāʿ*) were engraved as on the alidade of the *musātira*, its centre being the pole. The other face was fitted with an alidade on which altitude arguments are engraved as on the oblique horizon on the *shakkāziyya*, its centre being the zenith.[6] (This quadrant) was sold after his death, may God have mercy upon him.

{*Diagram*}[7]

<Text in the diagram:> <First quadrant:> For latitude 36° north. – [This quadrant has two threads; the first one] is (attached) at the centre, and the second one at the zenith. – <Second quadrant:> For latitude 36° north. – This quadrant has a single thread at the middle.

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[3] *al-Sukkar al-munabbat bi-l-ʿamal bi-l-rubʿ al-musammat*; the reading *manbat* should perhaps be preferred, since *al-sukkar al-manbat* has the well attested meaning of 'candied sugar'. Even though *al-sukkar al-munabbat* is not attested in this sense, it is necessary for the rhyme.

[4] *Qurʾān*, III, 167.

[5] This individual is unidentified.

[6] This statement does not imply that stereographic projection is involved, but simply that the altitude scales on each alidade are numbered in two directions in each case: on the first quadrant it is numbered from the extremity toward the centre of the alidade (as with the altitude circles of a *musātira* – see Ch. 54), and on the second quadrant from the centre toward the extremity of the alidade (as with the *shakkāziyya* – see Ch. 39 and Puig 1986, p. 49).

[7] See Plate 18.

TABLE T.2. Table for constructing the azimuthal quadrant for latitude 36° north

	Cancer				Aries				Capricorn		
T	*h*	az_s	*h*	*T*	*h*	*az*	*h*	*T*	*h*	*az*	*h*
6	4;17	10	54;50	6	4;51	0	0;00	6	[4];09	30	0;00
12	8;44	20	66;00	12	9;38	10	13;36	12	8;16	40	10;00
18	13;14	30	70;00	18	14;30	20	25;21	18	11;29	50	18;00
24	17;54	40	72;00	24	19;15	30	34;35	24	15;08	60	23;00
30	22;33	50	73;30	30	23;52	40	41;31	30	18;34	70	27;00
36	27;20	60	75;00	36	28;25	50	46;28	36	21;31	80	30;00
42	32;08	70	76;00	42	32;45	60	50;08	42	24;02	90	30;25
48	37;00	80	77;00	48	36;57	70	52;14	48	26;27		
54	41;50	90	77;30	54	40;54	80	53;26	54	28;12		
60	46;40	az_n		60	44;28	90	54;00	60	29;20		
66	51;30	10	30;00	66	47;37	Pisces		66	30;00		
72	56;12	20	17;00	72	50;17	*T*	*h*	71;39	30;25	ψ_s	h_m
78	60;54	30	0;00	78	52;20	78	41;00			10	46
84	65;32			84	53;30	Taurus				20	38
90	69;50	Gemini		90	54;00	*T*	*h*			ψ_n	h_m
96	73;41	*T*	*h*			96	64;00			10	62
102	76;14	102	73;00							20	70
108	77;00										
108;21	77;35										

This table was compiled from the *Tables of Time-arc*.

5 *On the construction of the complete northern astrolabe. (It is called complete) because its altitude circles are complete from south to north.*

pp. 63, 52 Trace a circle as (you did it) before. Place the ruler at the centre and trace a straight line (reaching) both sides of the circle. Find the distance[1] of the horizon from the pole as we have mentioned at the beginning, and we (can) determine (it) as well (by calculation ?) in that we take the vertical shadow of half the terrestrial latitude from the table. Add to it two thirds of it. Subtract one minute for each degree of the sum. The remainder will give you the desired result. Keep it in mind.

Then find the farthest distance of the horizon (from the pole) by taking the horizontal shadow of half the terrestrial latitude. Add to it two-thirds of it. Subtract from each degree of the sum one minute. The result will be the farthest distance of the horizon. Add to it the quantity you kept in mind, and take half of their sum: divide the radius of the circle (of the horizon) into this amount. From these divisions take the first quantity you kept in mind, starting from the (bottom) intersection of the circle on that line: this will be the centre of the mater. Place one leg (of the compass) at the centre and the other leg at

[1] The text has 'radius' (*passim*).

the circumference of the farthest circle,[2] and trace a complete circle: this will be the mater. Divide it into 360 equal parts. Trace (also) the equinoctial line. Place one leg of the compass at the centre and the other one at the intersection of the equinoctial line with the first circle, which is the horizon circle, and trace a circle: this will be the equatorial circle. Now trace the circles of both tropics as you did before. Construct the altitude circles from the table, and in the same way (construct) the azimuths, the hours, the rete, the ecliptic and the star (-pointers). There is no need for depression circles.

As we want to do it for latitude 36°, we have determined the shortest distance of the horizon, and we found $6;24^p$. We (also) found the farthest (distance) to be $60;32^p$. We have divided the radius of the largest circle (of the plate) by the amount of the farthest (distance) $60;32^p$, and from these parts we took $6;24^p$ in the direction of the pivot. We then added $60;32^p$ to $6;24^p$, and their sum is $66;56^p$. We took one half of it, which is $33;28^p$: this gives the (distance from the) centre of the horizon (i.e., its radius). If you want, (you can) divide (the distance) from the nearest radius to the farthest one in two halves, and this will (also) give you the centre of the horizon circle. If you wish, open (the compass) to half of that sum, that is $33;28^p$, and place one leg of the compass on one of the extremities of the horizon, and the other one where it cuts the line. This (again) will be the centre of the horizon. Trace a complete circle, which will be the circle of the horizon. Then divide the circle in four quadrants by another line, that is the equinoctial line. Place one leg of the compass at the centre and the other one upon the intersection of the horizon with the equinoctial line, and trace a circle: this will be for Aries. Do as you first did (for the rest of the construction). Its rete is as before, except that it should fit into the largest circle. God knows best.

{*Diagram*}

Plate of the complete northern astrolabe.

<Text in the diagram:> Latitude 36°. – East, West.

6 *On the construction of the southern astrolabe called the complete (astrolabe), because its altitude lines are complete between the northern and southern poles.*

First trace a circle, then place the ruler at the centre and trace a straight line joining both sides of that circle. Determine the nearest and farthest distances[1] of the horizon as we explained previously on the back of this page. Divide the radius of this circle by the farthest distance of the horizon, which is $60;32^p$, and in terms of these parts, open (the compass) to the nearest distance, which *pp. 63, 52*

[2] I.e., at the top of the horizon circle.

[1] The text has 'radius' (*passim*).

is $6;24^p$. Place one leg of the compass at the centre of this larger circle and make a mark with the other leg in the direction of the suspensory apparatus: this will be the position of the nearest (distance) of the horizon from the pole. Add the distances as we have mentioned: their sum will be $66;56^p$. We take one half of it, to obtain $33;28^p$. We then place one leg of the compass on one of both extremities (of the horizon) and the other one where it cuts the (vertical) line: this will be the centre of the horizon. Hold (the compass) fixed there and trace a complete circle, which will be the circle of the horizon. With another line let the circle (of the plate) be divided into four quadrants: (this) will be the equinoctial line. Place the compass at the centre and the other one upon the intersection of the horizon with the equinoctial line. Trace a circle with the compass, and it will be the circle of the equator. Perform this operation (according to the entries taken) from the table in which the southern altitude circles are written down. Whence the three day-circles are completed as well the marks (made with) the ruler, join them until you have completed all the altitude circles. Construct the azimuths as you have done in the case of the northern (astrolabe) and all of them will meet at the zenith.

{*Diagram*}

7 *On the construction of the complete astrolabic quadrants.*

pp. 63, 52 For the northern one, trace a circular arc and make a quadrant of it delimited by two lines: the eastern line and the meridian line. Divide one of them by the farthest distance[1] of the horizon, which is $60;32^p$ for a latitude of 36°. From that amount take the nearest (distance), which is $6;24^p$ and place one leg of the compass at the centre of the quadrant and the other one where it cuts the divided line. This will be the point of the nearest (distance of the) horizon from the pole. Add those mentioned radii and (their sum) will be $66;56^p$. Take one half of this, that is, $33;28^p$, from that amount with the opening of the compass. Place one leg of the compass on one edge of the horizon (circle) and the other one where it meets the divided line: this will be the centre of the horizon. Hold its leg fixed and trace a circular arc, which will be the arc of the horizon. Place one leg of the compass at the centre and the other one upon the intersection of the horizon with one of both lines. Trace a semicircle, which will represent the day-circles of Aries and Libra. In terms of that quantity, open (the compass) to the radius of the day-circle of Cancer, which is $12;54^p$, < and trace a semicircle, which will be the day-circle of Cancer. Open (the compass) to the radius of the day-circle of Capricorn, which is 60^p > and trace a circular arc from the horizon to the meridian line: this will be the day-circle of Capricorn.

[1] The text has 'radius' (*passim*).

If you wish (to trace) the altitude circles, take the hour-angle corresponding to the altitude arguments from the table. Take this amount in terms of the divisions of the outer scale,[2] starting at the meridian line. Place the ruler on the end of the (corresponding) number on the outer scale and make a mark on one of the three desired day-circles, namely, Aries, Cancer or Capricorn. When the marks for all three day-circles have been completed, join them as circular arcs, each of their arcs being semicircles. If (for a particular altitude circle) the marks have been completed for Aries (?) do this (same operation) for Taurus and Gemini, so that you can join the marks of the three day-circles, (and do that) until the altitude circles are completed.

If you want (to construct) the azimuths, determine the radius of the prime vertical, as (mentioned) before; its distance is 24;20^p. Open the compass (to this amount) and place one leg on the zenith and the other one where it meets the 'line of the pivot of the earth'.[3] Hold the compass fixed and trace a circular arc from the zenith to the horizon. Then open (the compass) to the time-arc corresponding to an azimuth (taken) at each ten degrees, and which is in the table. Place it on that day-circle for one of the three (and make a mark) in order (to obtain) all marks (which you join) until the azimuths are completed.

If you want to trace the hour-lines, divide all three day-circles into six (equal) parts and join the marks (thus produced); make dots on them so that they cannot be confused with the azimuths. The hour-lines on these two quadrants[4] are (traced) above the altitude circles.

The construction of the southern one is just as you have constructed the northern one, except that its horizon is above its centre. And for each of the two (kinds) there is a table for the construction of the altitude circles.

{*Diagram*}

8 *On the construction of the spiral astrolabe.*

Trace a circle and divide it into four quadrants. Trace the circles of Aries, Cancer and Capricorn as you did previously. Open the compass to the hour-angle that is (written) in the table. Place one leg of the compass at the intersection of one of the lines with that circle and the other one where it cuts the circle. Place the ruler there and on the centre and make a mark on the intersection of the side of the ruler with that circle, being one of the tropics or the equator. Join these marks and you will obtain the arcs of the altitude circles. Do this (operation) as you already did at the beginning. *pp. 74, 79*

[2] Literally 'arc of the quadrant', *passim*.
[3] Elsewhere this is abbreviated as 'line of the pivot'.
[4] I.e., the northern and southern ones. But the latter is not mentioned before the next sentence!

If you want the azimuths, trace them as you did before. Omitting them is (actually) more appropriate than drawing them, (for otherwise the instrument) would be obscure, as the arcs would run into each other. This (observation), however, is doubtful (i.e., not obvious) for someone who wants to find the azimuth from (this quadrant). But better than determining the azimuth from that figure is (to determine it) from the (scale) of the limb (*dāʾirat al-ḥujra*).[1] It will be mentioned among the entire chapters of the treatise (entitled) *The Astrolabe of the Desirous Which does not Need the Concealed Markings*.[2] Likewise for the hour-lines: they do not need to be drawn on it. (On this astrolabe) each quadrant (of the plate) must differ from another. (Furthermore) its hours are also determined from the circle of the limb.

For the rete, its construction is similar to what has been mentioned previously, except that any ecliptic point and its opposite point are only (represented) at the place of a zodiacal sign on a single ecliptical ring, I mean that the writing of the names of the twelve zodiacal signs goes forward and (then) backwards. (But) the best (retes) have two (separate) ecliptic rings.

{*Diagram*}

9 *On the construction of the* rūmī *astrolabe called the* shajjāriyya.

pp. 104, 109 Trace a circle and divide it into four quadrants. We (could) determine for it a table (for constructing the markings on it) from the tables (of the time-arc) mentioned, namely, for a location without latitude at the equinoxes, (but) we have found that (in this case) the altitude is equal to the time-arc, and for this reason we have omitted the table. Then (to construct the 'altitude circles',) we place the ruler on the 'pole of projection'[1] and on the graduation of the 'altitude circle'.[2] We mark off the intersection of the ruler with the 'suspension line',[3] and we keep it. We place one leg of the compass on the north-south line[4] and with the other leg we trace a semicircle[5] (passing through the mark on the 'suspension line' and whose extremities are) on (each) graduation of the greatest circle – which is the day-circle of Aries. We continue to do this until we have completed the 'altitude circles'.

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[1] It is not clear what is exactly meant by this 'circle of the limb' method. The translation of this sentence is problematic, but the meaning can be interpolated from similar statements occurring several times in the treatise: cf. Chapters 13, 20, 21, 22, 24, 27, 28, 31, 33, 34, 34, 35, 36, 37.

[2] This appears to be a different work by our author dealing with the use of astrolabes.

[1] I.e., each extremity of the horizontal diameter of the plate.

[2] I.e., the graduation along the rim that corresponds to the argument of each 'altitude circle'. Najm al-Dīn uses the terminology 'altitude and azimuth circles' to designate the parallels and meridians of the universal projection, by analogy with the standard astrolabe, since they are identical with these markings on an astrolabe plate for latitude 0°.

[3] I.e., the upper half of the vertical diameter. Cf. p. 49 of the commentary.

[4] I.e., the line coinciding with, and extending outside of the vertical diameter.

[5] These arcs are actually less than semicircles.

For the 'azimuths', place one leg of the compass on the line of the middle of the circle that intersects the line of the north and south points and trace an arc of circle with the other leg from north-south line $<\ldots>$[6] until you complete the arcs of azimuth.

To construct the rete, trace a circle of the size of the largest circle (of the plate) and divide it into four. Construct half of it with arcs like the azimuths and altitude circles, and the other half in its own way (*ʿalā ḥālatihi*, i.e., as a standard rete). The index (*murī al-ajzāʾ*) has to be at the extremity of the line passing through the centre and intersecting the line of the arcs (at right angle) (i.e., the horizontal diameter). This design is precisely that of the *shakkāziyya* (*sic*! read *shajjāriyya*).

The altitude circles on this astrolabe correspond to the day-circles on the *shakkāziyya*, and the azimuths correspond to the meridians. The *shakkāziyya* has no rete; only an inclined horizon or a thread is fitted on it, so it is not necessary for us to display it at another place (in this book).[7] This figure (of the plate) renders the figure (of the rete) superfluous. There is nothing more on it except the line of the longitude, which is the one on which the names of the zodiacal signs are written, and it is traced at (an angle to the equator equal to) the obliquity of the ecliptic.

{*Diagram*}[8]

Explanation of the construction of the 'belt of the stars' on the rete of the shajjāriyya. Place one leg of the compass at the centre of the plate and the other leg on the altitude circle corresponding to the declinations of the stars, and move the compass with this opening, so that you place one leg at the centre of the rete and the other one where it meets the line of the right ascension (of the star). It is necessary that the right ascension be smaller than 90° or greater than 270° if the declination is southerly, or (conversely) if the declination is northerly. Write on each star (-pointer) its name and direction.

For the ecliptic belt, place one leg of the compass at the centre of the plate and the other leg on (the altitude circle corresponding to) the obliquity of the ecliptic (counting from the outer circle). Move (the compass) so that you place one leg at the centre of the rete and the other leg where it cuts the (meridian) line above the centre. Make a mark. Widen the compass and place one leg on that mark and the other one on the (meridian) line under the centre. Move the leg that is on the mark towards the two points where the circle intersects the

[6] The arc must also pass through the mark for each graduation originally made on the vertical diameter and now transposed on the horizontal one.

[7] I.e., Ch. 39.

[8] See Plate 5

other line passing through the centre (i.e., the horizontal diameter). If it fits, trace a circular arc, which will correspond to the ecliptic. If not, try again by greater or smaller (openings of the compass) until it does fit. Trace another circular arc (lit., 'circle') to encompass (the regions of) the zodiacal signs (*li-tahūzu al-burūj*).[9] Place the ruler on the intersection of Capricorn and on the centre (of the rete) and trace a line that passes between both (arcs of) circles. Do this way (also) for Aquarius, Sagittarius and Scorpio. You have thus completed (the graduations) of the zodiacal signs. Write their names between both (arcs of) circle, from Libra to Pisces and again in the reverse direction from Aries to Virgo. Make the graduations of the parts of the ecliptic on the limit of the arc joining the greatest circle (*fī raʾs al-khaṭṭ muttaṣilan bi-l-dāʾirat al-kubra*).

The arcs of the rete are called 'horizons' on the *shajjāriyya*. It is necessary that the divisions of the arcs of the rete be different from the divisions of the arcs of the plate, for if the arcs of the plate are at each six degrees, it is necessary that the arcs of this rete be at each ten degrees, so that the arcs of the plates be visible through the arcs of the rete. This arrangement is according to the choice (*raʾy*) of the maker (of the instrument). The arcs of the rete are cut in (a plate of) brass, wood, or otherwise. A thread or an alidade can dispense with a rete, but the rete is much better, for it (embodies) the principle of the *shajjāriyya*, which is a universal (instrument).

{*Diagram*}

Rete of the *shajjāriyya*.[10]

[9] The verb حاز (first form) is here used in the sense "to encompass, to delimit" each twelve segments of the ecliptic belt within which the names of the zodiacal signs are engraved; compare the substantives *ḥawz* "espace, plage" and *ḥawza* "espace compris entre certaines limites" (Kazimirsky, *Dictionnaire Arabe-Français*, s.v.). The expression *(li-)yaḥūzu (asmāʾ al-burūj)* occurs several times in the treatise (in Chs. 9, 11 [twice], 15, 20, 21, 24, 27, 28, 33–36). Most of the time (eight occurrences) the subject of this verb is the circle or arc that bounds the ecliptic ring, but in five cases (Chs. 11 [second occurrence], 20, 21, 27, 28) the subject is a radial line that delimits a pair of zodiacal signs, i.e., which defines a frontier between them.

[10] In **D** the illustrations of Chapters 9 and 10 have been interchanged. Two notices in the margins of folios 80v and 81r warn the reader:

> This is the universal astrolabe. Its position is on the right page and the description of its construction is above-mentioned. However it has been placed here by mistake. [**D**:80r]

> This is the rete (*minṭaqat al-kawākib*). Its position is on the left page and the description of its construction is above-mentioned. However it has been placed here by mistake. [**D**:81r – see Plate 5]

10 *On the construction of the universal astrolabe invented in Mecca (Bakka) – May God Almighty exalt it! – in the year of (my) residence there, namely, the year 723 (Hijra) [= 1323].*[1]

When I arrived in Cairo, I found (one instrument of this kind) engraved on brass in the (manner of) construction of the countries of the Maghrib and attributed to the excellent *shaykh* Ibrāhīm ibn ʿAlī ibn Bāṣo al-Andalusī. I thus learned that he had preceded me in this. I got the knowledge of its construction and its use (*risāla*). I found it equivalent (to my own invention) in beauty and experience (? *li-l-khayr wa-l-khubr*). *pp. 109, 111*

If you want (to construct the universal astrolabe), trace a circle and divide it into four quadrants. Divide that circle into 360 equal parts: this will be the outer rim. Trace the three circles of declination as you did previously and construct the altitude circles as you did those of the *shajjāriyya*, except that the equatorial circle on the *shajjāriyya* is the largest one and here it is the middle one; (also construct) the azimuth circles as you did before, except that the zenith here is located on the equatorial circle. Half of this design can dispense with (using) the whole, as the maker sees fit, according to whether he wants to make one half of it or to make the whole of it.

It is not possible to make the hour-lines, since it is impossible to trace the seasonal hours on universal figures, except when something of the same kind is (displayed) together with it (?).[2]

The rete of that astrolabe is the ordinary rete already mentioned, and its construction is (explained in) the first Chapter, except that it is necessary to write on each star (-pointer) the sign of its declination together with its name: if it is northerly, you write ش on it, and if it is southerly, you write جـ on it, in order to distinguish southern stars from northern ones whilst you are using this instrument with (appropriate) instructions (*waqt al-ʿamal bi-risāla hādhihi al-āla*), namely, (as if using an astrolabe with) altitude circles for latitude zero and (an astrolabe with) altitude circles for latitude 90°. To God we call for help.

{*Diagram*}

Diagram of the universal astrolabe. Its rete is like the regular one.

11 *On the construction of the cruciform astrolabe.*

It (i.e., its plate) is the first northern figure mentioned in the first Chapter. We do not need to repeat its construction but (to mention that) its rete resembles *p. 79*

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[1] Bakka is an alternative name for Mecca, which occurs once in the Qurʾān (III, 96).

[2] The intended meaning seems to be: except when these hour-lines are drawn in relation to one specific horizon and specified to be valid for one latitude only.

a cross[1] and thus it is called the cruciform (astrolabe). We need to construct its rete and we (now) explain its design.

If you want (to do) that, trace a circle and divide it into four quadrants (defined) by four straight lines. Place the compass at the ecliptic pole and with the other one trace a semi-circle joining both poles of projection and the radius of the horizon. Trace (another) circle inside it that will encompass the names of the zodiacal signs.[2] Place the ruler at the centre and on the ascensions of the northern signs, and trace a line between both of these circles and write on them the names of the zodiacal signs. Open the compass to the meridian altitude (of the sun on the meridian line of an astrolabic plate) at the beginning of each of the following three zodiacal signs: Libra, Scorpio and Sagittarius. Place (one leg of) the compass at the centre of the rete and the other one on the line that passes through the beginning of Cancer in the opposite direction. Make a mark (there) and trace a line separating each sign (*yaḥūzu bayna al-burūj*[3]).

Make the star-pointers as you made them before, according to their mediations, declinations and directions. Write on each of these stars their name. Then this rete, not having its circle (complete), will be (like) a cross. Most astrolabes are named after the design of their retes. Now the rete may be made according to another manner, since (some of) the zodiacal signs can be written along the diameter of the rete. This is better since the (right) ascension of the signs can be known with this (ecliptic) ring. If (the ascensions) are not on it,[4], it is possible to find neither the right ascensions of the signs nor their oblique ascensions. And likewise the ascendant, descendant and mediation can be found with a little bit of ingenuity (*maʿa yasīr min al-taḥayyul*). Other (operations) are difficult with (this instrument), as we have mentioned.

{*Diagram*}

Rete of the cruciform (astrolabe), for any latitude for which you have drawn its plate.

12 *On the construction of the crab astrolabe, which is named after the construction of its rete.*

p. 75 Trace a circle and divide it into four quadrants. Draw the day-circles of the equator and tropics. Make the marks of the altitude circles using the table we have mentioned at the beginning and join those marks to the left and to the right, whereas some of them are northerly and some of them southerly: Its altitude circles are in correspondence to another: the northern ones are made

[1] The text has: 'crossing' (*muṣallab*)
[2] Cf. note 9 on p. 246.
[3] Cf. note 9 on p. 246.
[4] As a table of ascensions engraved on the astrolabe, as advocated by al-Bīrūnī?

of northern ones and the southern ones of southern ones. Write on them their numbering and the latitude of the plate for which you engraved it. We mention its rete on the next page and we illustrate it after the drawing of the plate. Some of the eminent (scholars) had mentioned that the crab (astrolabe) be a southern (projection) and that its rete differs from what we have illustrated. For my part I have looked at an illustration of its rete in the well-known book of al-Bīrūnī and I found it problematic *bi-shayʾ min dhahāb (?)*, so I chose to depict on the rete stars which are appropriate instead of (things involving) *dhahāb* (deceit?). They will be mentioned after this chapter.

{*Diagram*}

Plate of the crab (astrolabe).

<Text in the diagram:> Latitude 36°. – East, West.

Explanation of the construction of the rete. Trace a circle and divide it into four quadrants by two (perpendicular) diameters. Place the compass at the centre of the plate and the other one on the equatorial circle and move the compass with this opening so that you place it on the centre of the rete. Make a mark with the other leg on one of both diameters, namely, (the one going) in the eastern and western directions. Do it also for Cancer and mark the other diameter in the northern and southern directions. Place the compass on the north-south line and join the three marks to the right and left (on both sides). This will be the ecliptic. Then place one leg of the compass at the centre of the plate already mentioned and the other leg upon the declination of the star on the day-circles without concern for the direction of the declination, according to the choice of the maker (of the instrument), whether he wants to make it inside of the equatorial circle or outside of it. Transfer (this quantity) with the compass onto the rete and make a mark on the ascension of the star: this will be its location, so mark (the star-pointer) and write the (star's) name on it.

{*Diagram*}

Illustration of the crab rete.

13 *On the construction of the northern 'counterbalancing' astrolabe.*

Trace a circle and divide it into four quadrants. Trace the three day-circles as p. 75
you did before. From the northern table which was derived from the *Tables of Time-arc*, take the time-arc[1] for each altitude circle. Mark (it) at the location of that time-arc, each on its respective day-circle, and fix the marks. Then place one leg of the compass on the 'suspension line' and the other leg upon the three marks (of some altitude circle), if they fit, and if not, widen or narrow (the opening of) the compass until you can join the three marks that have been made: this will be the altitude circle that corresponds to this time-arc.

[1] In fact the table in Ch. 1 displays the hour-angle.

The (construction of) azimuth (circles), is as before, and we did not leave it out, although the component parts (*ālāt*) get obscured (by having too many markings on them[2]). Better than to determine the azimuth from these figures[3] is (to determine it) from the circle of the limb. Its explanation will follow in this treatise, God Almighty willing.[4]

{*Diagram*}

Plate of the northern 'counterbalancing' astrolabe.

Explanation of the rete of the northern counterbalancing (astrolabe). It is (also) the rete of the myrtle and anemone (astrolabes), whose explanations will follow, God Almighty willing. If you want (to construct it), trace a circle and divide it into four quadrants. Then determine the position of the ecliptic pole, and trace with the compass a circular arc at the left and at the right. Place the ruler at the right ascension of each zodiacal sign and leave a mark on that arc. Place the ruler at the centre and trace a straight line upon that arc: this will be the position of the ecliptic sign. Write its name on it.

The construction of the stars is like the usual (procedure), which has been mentioned already, namely, by (using) the declination and right ascension. Write the name by which it is best known (*ismuhu al-maʿlūm*) on each of them. The star (pointers) may be drawn in the direction of the zodiacal signs corresponding to their directions. Or they may be drawn in the direction (of the signs) opposite to theirs, similarly to what we have illustrated in the diagram. Or the stars with one or the other declination may be drawn on all the signs with their individual mediations. It can bear many more stars, yet you have to write their mediations on them.

{*Diagram*}

14 *On the construction of the myrtle astrolabe, which is (also the plate of) the drum one, each of them having its own rete.*

p. 75 We have already mentioned the rete of the myrtle (astrolabe): it is composed of the rete of a northern (astrolabe), whereby the stars south of the tropic of Capricorn are left out on it.[1] For the rete of the drum (astrolabe), we illustrate it on the next page.

If you want (to construct the plate), (you should know that) it is the same as a north-south one, and these have already been mentioned. When you combine both of them on a single plate, this figure results. If you want to

[2] Cf. Chapter 8.
[3] I.e., the figures of astrolabic plates with mixed projections.
[4] See Chapter 31.
[1] To make sense, the last part of this sentence should actually read 'whereby the zodiacal signs south of the tropic of Aries are left out on it'.

divide it, proceed as before for the construction of the azimuths. You may likewise draw a special azimuth plate, which can be used on all astrolabes. It will be mentioned later, God Almighty willing.

{*Diagram*}

Diagram of the plate of the myrtle astrolabe.
Diagram of the plate of the drum astrolabe.

Explanation of the construction of the rete of the drum (astrolabe). Trace a circle and divide it into four quadrants. Determine the position of the ecliptic pole, and place one leg of the compass on it. With the (other) leg trace a circle from one of the diameters to the other one,[2] and do the same in the other direction: this will be the ecliptic belt. Place the ruler upon the right ascension of each zodiacal sign and at the pole of the rete, and trace a straight line: this will give the mark of that zodiacal sign. As for the stars, their construction is (achieved) with their right ascensions and declinations as described above. Understand this and you will get it right, God Almighty willing.

{*Diagram*}

Rete of the south-north drum (astrolabe).

15 *On the construction of the (complete) south-north astrolabe, without having to be concerned with looking at the rete.*

Trace a circle and divide it into four quadrants. You then divide one of the diameters into $60;32^p$, which is known from Chapter 6, on the construction of the complete southern (astrolabe). Then take the diameter of the equator in terms of these parts, namely, $19;39^p$. Trace a circle with the compass, which will be the circle of the equator. Next take $12;54^p$ for the circle of Capricorn[1] and 30^p for that of Cancer.[2] Then take the <nearest> distance[3] of the horizon already known, which is $6;24^p$. Place one leg of the compass at the centre and make a mark with the other leg in the direction of the 'suspension line'. Place one leg of the compass on the meridian line and by successive approximations with the other leg try to join the two poles of projection[4] and the mark for the horizon. Draw a complete circle with the other leg: this will be the horizon. Make on the day-circles the three marks corresponding to the hour-angle taken from the northern table, and join the marks until all the

pp. 63, 52

[2] I.e., from one side of the horizontal diameter to the other side.
[1] The text has 'Cancer'.
[2] The text has 'Capricorn'.
[3] The text has 'radius'.
[4] I.e., the two intersections of the equatorial circle with the horizontal diameter.

northern altitude circles have been completed. Operate in the same way for the southern altitude circles, their extremities (reaching the circle of) Cancer.

{*Diagram*}

The (complete) south-north (astrolabe). Its rete has the same size (? *bi-rasmihā*).[5]

<Text in the diagram:> The author of this book invented it.

Explanation of the construction of the rete. Trace a circle as large as the largest one on the plate and divide it into four quadrants. Open the compass to the distance between the circles of both tropics with different directions along the diameter of the plate that has been drawn. Transfer this quantity onto the ecliptic pole and with the compass trace a circle, after having marked the positions of both tropics on the rete, their midpoint being the ecliptic pole. Trace a circle just below it to encompass the names of the zodiacal signs.[6] To make the stars, place the ruler upon the ascension of the star. Place one leg of the compass at the centre of the plate and the other leg on the altitude circle corresponding to its declination, in its direction, and once again transfer (the compass) onto the centre of the rete, and the other one where it cuts the side of the ruler: this will be the position (of the star). Write the name by which it is best known on it. It is necessary that northern stars be outside of the ecliptic, and that southern stars be inside of it, as we represented it here. And it can bear many stars.

{*Diagram*}[7]

Diagram of the rete of the (complete) south-north[8] astrolabe.

16 *On the construction of the anemone astrolabe and its rete.*

p. 75 Draw a circle and divide it into four quadrants. Trace the circles of the equator and tropics, and do as you did in the case of the northern altitude circles that have been first determined from the table. Join the three marks that are on the three mentioned day- circles, (starting) from the 'suspension line' and underneath it. Likewise for the western line.

{*Diagram*}

Plate of the anemone. Its rete is like that of the myrtle and the counterbalancing (astrolabe). Its construction has been mentioned before.

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[5] I.e., the shape and size of the rete corresponds to that of the plate?

[6] Cf. note 9 on p. 246.

[7] See Plate 17.

[8] The text has 'north-south'.

17 *On the construction of the solid astrolabe.*

It is called solid because its stars (as well as the ecliptic belt) are 'solidified' *p. 66* upon the plate. Trace a circle and divide it into four quadrants. You construct it as you first did the northern one. As for the stars and the ecliptic, you draw them as before. All of the stars are drawn between the hour-lines,[1] and the rete is drawn over the altitude circles and underneath them.

{*Diagram*}

Plate of the solid astrolabe. Its rete is (replaced by) the alidade.

<Text in the diagram:> Latitude 36°. – First, second, . . . , eleventh (hour).

18 *On the construction of the skiff astrolabe.*

You should know that its plate is related to the shape of the rete. Trace a circle *pp. 75, 79* and divide it into four quadrants with two perpendicular diameters. Make the circles of equator and of both tropics. Mark the position of the altitude circles from the table of the time-arc mentioned at the beginning. Place one leg of the compass at the pole of projection and make each mark of the altitude circles. Mark the intersection of the ruler with the 'suspension line', and trace the arc of the horizon in the direction of the suspensory apparatus and underneath it. Join these marks, namely, the marks of the altitude circles, and number them towards the 'suspension line' and underneath it. As for the azimuths, leaving them out is more appropriate than constructing them. Understand this and you will get it right.

{*Diagram*}

Plate of the skiff (astrolabe) for latitude 36°.

<Text in the diagram:> East, West.

For the construction of the rete, determine the position of the ecliptic pole. Place one leg of the compass upon it and the other leg on the largest circle, and trace a circular arc within one of the quadrants. Move the compass with this opening and place one leg upon the pole at the other side, and do the same operation. Move again (the compass) with this opening and place one of its legs upon the pole at the other side and trace a circular arc (within a single quadrant). Move again (the compass) with this opening and do the operation, tracing a circular arc. The ecliptic is complete. Write the names of the zodiacal signs on it. As for the stars, (they are to be constructed) as previously, with their declinations and right ascensions.

{*Diagram*}

Diagram of the rete of the skiff astrolabe, which has a very nice form.

[1] I.e., underneath the horizon.

19 *On the construction of the jar astrolabe.*

p. 76 Trace a circle and divide it into four quadrants. Open (the compass) to the hour-angle for each altitude circle at the three day-circles, and join (the resulting marks) inside of the equatorial circle, on the side of the suspensory apparatus and (those that are) underneath it, like the southern altitude circles are (usually) made, and join (the marks) outside of the equator like the northern altitude circles already mentioned are made. The plate is thus completed. God Almighty willing.

{*Diagram*}

Plate of the jar (astrolabe) for latitude 36°.

<Text in the diagram:> East, West.

To construct the rete, trace a circle and divide it into four quadrants. Open (the compass) to the radius of the ecliptic, and trace two invisible circles (*dāʾira wahmiyya*)[1] (the second one with a radius slightly smaller than the ecliptic). Place the ruler at the centre and upon the right ascension of each zodiacal sign, and make marks on both circles. Write the names of the zodiacal signs between both. As for the stars, (they are to be constructed) as previously, with their declinations and right ascensions. Write their names and directions on each of them.

{*Diagram*}

Rete of the jar (astrolabe).

20 *On the construction of the bull astrolabe.*

p. 76 Trace a circle and divide it into four quadrants. From the table of northern altitude circles take the entry corresponding to each altitude circle for Aries and for Cancer, and mark these time-arcs on each of these two day-circles, starting at the horizon. Take again from the table of altitude circles the entry corresponding to each altitude circle for Capricorn, and likewise mark it on its day-circle. Place one leg of the compass on the ‘suspension line’, and join the three marks. Number the altitude circles. As for the construction of the azimuths, it is as (explained) before. But it is nicer to determine (them) with the circle of the limb or with the azimuth plate, whose explanation will come later (in this book).[1]

[1] The adjective ‘invisible’ applied to a geometrical object means that is should serve as an auxiliary drawing in the construction, but should not be visible in the final figure. This can be achieved either by erasing it afterward, or by marking it as a light scratch on the paper. In manuscript **D** (and presumably also on manuscript **P**) such invisible construction lines marked with a knife or with a sharp point can be seen on some of the diagrams.

[1] See Ch. 31.

{*Diagram*}

Plate of the bull (astrolabe) for latitude 36°.

To construct the rete, trace a circle and divide it into four quadrants. Determine the position of the ecliptic pole. Place one leg of the compass on it, and with the other leg trace an invisible circle. Transfer (the compass) with their opening onto the other line, and trace (again) an invisible line. Place the ruler upon the right ascension of each zodiacal sign and at the centre, and trace invisible straight lines. Place one leg (of the compass) at the centre and trace another arc with the <other> leg, below the first arc, until the invisible line that separates each zodiacal sign.[2] Write on it the name of each sign. As for the stars, (their construction) makes use of their declinations and right ascensions. Write its name on each star (-pointer). Give to this rete a shape resembling that of a bull. The best (kind) has two stars on the two horns.

{*Diagram*}

Diagram of the rete of the bull astrolabe.

21 *On the construction of the tortoise[1] astrolabe.*

Trace a circle and divide it into four quadrants. Draw the three day-circles. *p. 77*
From the table take the time-arc corresponding to each altitude circle. Place the ruler upon the divisions of the largest circle at the time-arc for that altitude circle, and at the centre. Make a mark upon each of their day-circles. Once the marks of the altitude circles are completed, join them with the compass, inside the equatorial circle, and outside of it. When the altitude circles are completed, number them. As for the azimuths, (their construction) is as (explained) before, (but) the best (procedure) is (to determine the azimuth) with (the scale of) the limb.

{*Diagram*}

Plate of the tortoise (astrolabe) for latitude 36°.

To construct the rete, trace a circle and divide it into four quadrants. Determine the position of the ecliptic pole. Place one leg of the compass upon this point. Trace an invisible circle at the right and at the left <within the first circle>. Place the ruler upon the right ascension of each single zodiacal sign and at the centre, and trace straight lines between the two arcs to delimit the

[2] Cf. note 9 on p. 246.

[1] See p. 41 of the introduction.

names of the zodiacal signs.[2] As for the stars, (they are to be constructed) as previously, with their declinations and right ascensions. Write on each star (-pointer) the name by which it is best known. The shape of the rete resembles a tortoise. It is better The best (kind) has two stars.

{*Diagram*}

Diagram of the rete of the tortoise astrolabe.

22 *On the construction of the buffalo astrolabe.*

p. 77 Trace a circle and divide it into four quadrants. Divide the largest circle into 90 equal parts. From the tables take the time-arc for each altitude circle, I mean from both the northern and southern tables, at the equinox and at both solstices. Mark the three day-circles, and join the marks at the left and at the right, until the altitude circles have been completed. Number them. As for the azimuths, (their construction) is as (explained) before, (but) it is better to determine (them) from (the scale of) the limb.

{*Diagram*}

Plate of the buffalo (astrolabe).

To construct the rete, trace a circle and divide it into four quadrants. Determine the position of the ecliptic pole. Place one leg of the compass upon this point. Trace an invisible circle and draw an arc from the largest circle to the ascension of the end of Pisces. And do the same for the other side. With the compass, transfer its quantity onto the diameter. Do like this for all four quadrants. Write the names of each zodiacal sign on them. As for the stars, determine their declinations and right ascensions from the ascension table, and do as before. Write on each star (-pointer) the name by which it is best known.

{*Diagram*}

Diagram of the rete of the buffalo astrolabe.

23 *On the construction of the cup (*hanābī[1]*) astrolabe.*

p. 77 Trace a circle and divide it into four quadrants. Draw the three day-circles.

[2] Cf. note 9 on p. 246.

[1] See Dozy, *Supplément*, s.v. هناب: "*coupe* [à boire]". This word of medieval European origin (cf. old German hnapf and modern German Napf, old French hanap, old Italian anappo), presumably passed into Arabic at the period of the Crusades; it is frequently attested in Mamluk sources: see Quatremère, *Mamlouks* I.2, p. 211, and *Alf layla wa-layla*, 49:25.

Do as you did previously with the southern one. Mark the diameter on both sides of the centre, and join the altitude circles that you have marked from calculation of a numerical table for the southern altitude circles. It looks like the hollow of a cup from (?) the opposite altitude circle. This design is the first (?) rete that has been invented by the author of this book at the date (*taʾrīkh*) mentioned.

{*Diagram*}

Plate of the cup (astrolabe) for latitude 36°.

< Text in the diagram: > This design was invented by the author of this book.

To construct the rete, < trace a circle and divide it into four quadrants. > Determine the position of the ecliptic pole. Trace two invisible circles and mark the right ascension of each zodiacal sign. Place the ruler at the centre and on the mark, and trace an invisible straight line. Place one leg of the compass upon the ecliptic pole, and with the other leg trace a circular arc, which will be what you are looking for. The construction of the stars (is achieved) as before by using their declinations, directions and right ascensions. Write on each star (-pointer) the name by which it is best known.

{*Diagram*}

Rete of the cup (astrolabe).

24 *On the construction of the melon astrolabe.*

Trace a circle, which will be the circle of Capricorn, and divide it into four quadrants by two perpendicular diameters. Trace the three circles as before: these will be the two tropics and the equator. Determine the hour-angle from the table for the altitude corresponding to the numbering of each altitude circle. Count this quantity (on the limb), beginning at the suspensory apparatus, for each of the three day-circles, < and mark it off on them >. Place one leg of the compass upon these three marks and the other leg on the 'suspension line'. By successive approximations with the compass, try to join these marks between the day-circle of one of the tropics and that of the equator. Number the altitude circles and write the terrestrial latitude of your choice. As for the azimuths, (their construction) has been mentioned before. But it is better (to determine the azimuth) with (the scale of) the limb or with the azimuthal plate already mentioned. *pp. 77, 82*

As for the hours, determine the altitude of the hours from the *Tables of Time-arc*, or from the forthcoming table. Mark each of the three day-circles with the three entries (found) in terms of altitude. Join these three marks with the compass: these will be the arcs of the hours, which were first left out.

I have found some difficulty concerning this (astrolabic) design in al-Bīrūnī,[1] and there is discrepancy among the scholars (concerning it). I conceived this after I realised the difference in opinion among them.[2] I found it (i.e., the 'classical' melon astrolabe) to resemble the spherical astrolabe. One curve on it has the aspect of the horizon. It is not (derived) from the figures of (standard astrolabic) plates, and it does not have the property of their use. Some of the eminent men of this art have striven to (understand?) it. Fortune be upon whoever created it! In this book of mine I have left it out, and I substituted this figure for it.

{*Diagram*}

Plate of the melon (astrolabe) for latitude 36°.

<Text in the diagram:> This figure has been invented by the author of this book as a substitution to the plate of al-Bīrūnī.

To construct its rete, open (the compass) to the distance between the tropics on one of the diameters. Transfer it with (this) opening, and trace a section of a circular arc.[3] Then open (the compass) to the distance between the poles. Place one leg of the compass at the centre of the arc section and the other one where it cuts the line parallel to the centre of the arc (?): this will be the pole of the plate. Then place the ruler on it and on the right ascension of each zodiacal sign. Make a mark on the arc. Trace <another> circular arc <inside the first one>, which will encompass the names of the zodiacal signs.[4]

As for the stars, in some cases they are located on the rete, and in other cases they are located on the plate, according to the preference of the maker (of this instrument): but it is better to place them on the rete. This requires using the declinations, directions and right ascensions of each of them. Write on each star (-pointer) the name by which it is best known.

{*Diagram*}

The rete of the melon (astrolabe) of al-Bīrūnī.

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[1] Najm al-Dīn is obviously referring to the passage on the melon astrolabe that occurs in al-Bīrūnī's *Istīʿāb*; this passage is edited and translated in Kennedy, Kunitzsch & Lorch 1999, pp. 184–201.

[2] al-Bīrūnī reports of a controversy between al-Farghānī, Muḥammad ibn Mūsā ibn Shākir, on the one side, and al-Kindī, on the other side. See Kennedy, Kunitzsch & Lorch 1999, pp. 5, 178–211. To this should be added the opinion of al-Marrākushī, who supported al-Farghānī and Muḥammad ibn Mūsā: see al-Marrākushī, *Jāmiʿ*, I, p. 2 and Sédillot, *Traité*, pp. 57–58. Ironically, al-Marrākushī devoted a chapter on the construction of this instrument: see p. 65 of the commentary.

[3] In fact, a semicircle, as can be inferred from the illustration.

[4] Cf. note 9 on p. 246.

25 *On the construction of the spherical astrolabe.*

Trace a circle at the middle of the sphere (i.e., a meridian). Mark the two poles of that circle and mark the circle at each altitude (argument), using the tables: but the operation turns out to correspond to (finding the time-arc) at the equinox for a location with no latitude, and we found that the time-arc is then equal to the altitude. Divide the line of the poles (i.e., the meridian semicircle) into 180 equal parts. Place one leg of the compass at the centre of the sphere and the other leg upon each of its divisions, and trace a circle with the compass: this will be the altitude circle itself. If you want the azimuth, trace radial lines from the circular divisions of the sphere to the centre. You thus have made the azimuth lines. Number them. This is the construction of the sphere set on a supporting ring (? *kursī*). For the rete of that astrolabe, it is like the usual one, except that it is spherical (*muqabbaba*), hence it is not possible to illustrate it. *p. 62*

Be aware that the sphere actually does not require altitude or azimuth circles, for the meridian arc serves as a replacement for the altitude circles, and the movable arc section on the face of the sphere serves as a replacement for the azimuth circles. It only needs the arcs of the zodiacal signs (i.e., longitude circles at each 30°), the equatorial circle and their respective poles, as well as the horizon circle, which is divided on the *kursī* into 360 (parts), each quadrant having 90 (of these).

{*Diagram*}

The spherical astrolabe.

26 *On the construction of (the plate of) the horizons, which is called the universal one.*

Trace a circle and divide it into four quadrants. Then determine the half excess (of daylight) at one of the solstices, at each 10°, or otherwise, from the tables of half excesses. Take its value in parts of the (circumference of the) larger circle, and do the marks of the half excesses. Place the ruler on each mark and at the centre of the plate, and make a mark at the side of the ruler on the circle of Aries. Place the ruler at the pole of projection and on the mark of Aries, and leave a mark at the side of the ruler on the quadrature line (*khaṭṭ al-tarbīʿ*[1]), in all four directions. Place one leg of the compass upon one of the quadrature lines and the other leg upon the marks falling on the quadrature line and on the pole of projection. Trace a circular arc from the quadrature line to the larger circle. And if you want, (simply) join the marks of half excesses with the two poles of projection: this is easier that the first (method). *p. 60*

[1] This term refers to the two perpendicular diameters of the plate.

{*Diagram*}

Diagram of (the plate of) the horizons, from latitude zero to latitude 90°.

27 *On the construction of the frog astrolabe, invented (by the author).*

p. 77 Trace a circle and divide it into four quadrants. Trace the three day-circles. From the table of the altitude circles, take the value (of the hour-angle) corresponding to each altitude circle for Aries. Take this value in terms of divisions of the equatorial circle. Do the same for the two tropics, and join the three marks inside of the equatorial circle and outside of it, until the altitude circles are completed. Number them. As for the azimuths, leaving them out is more appropriate < than constructing them >. It is better to determine (them) from the azimuthal circle or from the (scale on the) limb, (as described in) < one of > the forthcoming chapters of the treatise.[1]

{*Diagram*}

Plate of the frog (astrolabe) for latitude 36°.

For the rete, trace a circle and divide it into four quadrants. Determine the location of the ecliptic pole. Place one leg of the compass on it, then trace an invisible circle at the right and at the left, and place the ruler upon the right ascension of each individual zodiacal sign, and upon the centre. < Trace > straight lines between the two arcs to delimit the names of the zodiacal signs.[2] For the stars, place one leg of the compass at the centre of the plate and the other leg upon the altitude circle of the star's declination, and transfer it (onto the rete) so that one leg of the compass be at the centre of the rete and the other one where it cuts the line of the star's right ascension: this will be its location.

{*Diagram*}[3]

Rete of the frog (astrolabe).

28 *On the construction of the eagle astrolabe, invented (by the author).*

p. 77 Trace a circle and divide it into four quadrants. Trace the three day-circles. Then from the table for the altitude circles take the entry corresponding to each altitude circle for Aries, and take this quantity in parts of the day-circle of Aries. Do the same for both tropics. Join the three marks inside the circle

[1] The azimuthal plate is featured in Ch. 31. Cf. Ch. 8.
[2] Cf. note 9 on p. 246.
[3] See Plate 2.

of Aries and outside of it, until the altitude circles are completed. As for the azimuths, leaving them out is more appropriate <than constructing them>. It is better to determine (them) from the azimuthal circle or from the (scale on the) limb, (as described in) <one of> the forthcoming chapters of the treatise.

{*Diagram*}

Plate of the eagle (astrolabe) for latitude 36°.

<Text in the diagram:> Invented by the author of this book.[1]

For the rete, trace a circle and divide it into four quadrants. Determine the location of the ecliptic pole. Place one leg of the compass on it, then trace an invisible circle at the right and at the left, and place the ruler at the right ascension of each individual zodiacal sign, and at the centre. <Trace> straight lines between the two arcs to delimit the names of the zodiacal signs.[2] For the stars, place one leg of the compass at the centre of the plate and the other leg upon the altitude circle of the star's declination, and transfer it (onto the rete) so that one leg of the compass be at the centre of the rete and the other one where it cuts the line of the star's right ascension: this will be its location.

{*Diagram*}

Rete of the eagle (astrolabe).

29 *On the construction of the* zarqālliyya[1].

It involves constructing one *shakkāziyya* on top of another *shakkāziyya*, but the arcs of one do not coincide with the arcs of the other. *pp. 101, 109*

If you want to do that, trace a circle and divide it into four quadrants by two perpendicular diameters. Place the ruler (successively) on the two points of the intersection of a diameter with this circle[2] and on each of the divisions of its (outer scale). Make a mark on the other diameter intersecting the side of the ruler. Do this until all numbers of the outer scale[3] are completed. Then place the compass on the line of the marks and move one leg back and forth until you can join these marks with the (respective) divisions of the circumference, if you wish at each 5°, or at each 6°, or otherwise. The day-circles are thus completed. Now do exactly the same for the meridians.[4]

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[1] The illustration in **D** bears this line of prayer in a later handwriting: "O my Master! O the Only One! My Master! The Eternal! O ʿAlī! ......" [The last two words are illegible].

[2] Cf. note 9 on p. 246.

[1] In both copies this word is constantly spelled *al-zarqāla*, and we have left it untouched in the edition: see the remarks on p. 103.

[2] I.e., on one of its extremities. The text has 'of one of the two lines'.

[3] Literally 'all numbers of the division of the circle'.

[4] This time, however, the circular arcs must join each of these marks and the two poles.

<. . . > Divide this circle according to the divisions of the first circle, and do as you did before; the (angle) between the longitude line and the quadrature line,[5] I mean between the poles, has to correspond to the obliquity of the ecliptic. Write the values of the day-circles and of the meridians on them.[6] It is also necessary to have on it the line of the inclined horizon, which is divided according to the (previous) divisions.

On the *shakkāziyya* you write the names of the zodiacal signs on the longitude line or on the inclined horizon, but on this instrument you do not write the names of the zodiacal signs. The longitude of the sun can be found from the instrument without writing (the names on it). On the back of this instrument is can be constructed the instrument known as *al-muʿtariḍa*, and its drawing is done by geometry or by calculation. If you want (you can take it) from this book, and we shall mention it later, God Almighty willing.[7]

{*Diagram*}

The figure of the *zarqālliyya*, which is one of the universal instruments.

<Text in the diagram:> Northern equatorial pole. – Southern equatorial pole. – Northern ecliptic pole. – Southern ecliptic pole.

30 *On the construction of the observational astrolabe, that is the armillary sphere.*

p. 221 Trace a circle and divide it into four equal parts, each part having 90 divisions. Number their arguments. Trace a circle smaller than the first one and proceed in the same way. Trace an arc in the middle: this will be position of the middle circle. On the instrument, there is a complete circle. It is not possible to represent (this circle) on paper, except in the way that you see it (here). This is not known from (using) the tables, but rather by means of geometry and (geometrical) quantities (*al-qisma*).

We only included it in our book, because it is the base of all the other (instruments) we have (described and) illustrated. The instruments presented so far are . . . (?) the declination of the sun (*al-mayl*) and stars (*al-buʿd*) and the (right) ascension. If these (quantities) are unknown, we need this observational instrument: indeed, when both the declination and the ascension are unknown, it is not possible for us to be dispensed from (using) this observational instrument, which has seven rings, (although) it is (also) said that there are nine, each of them (then becoming) tightier to each other. Its size (?) (*futḥa*) is like (that of) the sphere.

[5] I.e., the vertical diameter.
[6] I.e., the second set of markings.
[7] Unfortunately, this promise has not been hold by the author.

{*Diagram*}

Armillary sphere, also called the observational (astrolabe).

31 *On the construction of the azimuth circle, which is basic to most of the instruments explained.*

On most of these instruments there is no plate with the azimuths. The azimuth can be determined from such a (circle) or with the circle of the limb. It is necessary that (these markings) be on some of the plates of the astrolabe. If you want to construct it, trace a circle. Determine the time-arc from the table for each 10° of the azimuth, and mark its value on the circumference of the large circle.[1] Open the compass to the distance of the zenith from the centre of the plate, and place one leg of the compass at the centre of the plate and the other one on the (vertical) diameter (*khaṭṭ al-tarbīʿ*): this is the point of the zenith. Place one leg of the compass on the (vertical) diameter and the other leg on the zenith and, by successive approximations with the compass, join the two poles of projection[2] with the zenith: this will be the prime meridian. Trace its east-west line.[3] Move the compass until you can place its legs upon the zenith and upon each mark of (the azimuth). Hold one leg of the compass fixed on the eastern line of the azimuth circle, and trace an arc from the zenith to both sides of that circle. Number them. The construction of that plate is completed. *pp. 54, 57*

{*Diagram*}

The azimuth plate for latitude 36° south and north.

32 *On the construction of the* mubakkash.[1]

Trace a circle and divide it into four quadrants. Draw the circles of Aries, Cancer and Capricorn as you did previously, and divide the largest circle into 360 (equal) parts, each quadrant into 90 (parts). Place the ruler on the 30th division in the eastern (quadrant) and at the centre, and trace an invisible line. Place one leg of the compass on the western line and the other leg at the intersection of the invisible line with the circle of Cancer. Trace an arc going to the largest circle, at the point of intersection with the western point, if this is possible. If not, then move the compass forwards and backwards until you *p. 223*

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[1] In fact this should be the equatorial circle.

[2] I.e., the east and west points.

[3] I.e., a line parallel to the east-west line which passes through its centre. Cf. Ch. 1.

[1] This mysterious word defies any obvious explanation. In the Maghrib *bukkūsh* means dumb (in the sense of lacking the power of speech), whereas in modern Egyptian Arabic the word *bakash* has the sense of ‘trickery, bluffing’, and the verb *bakkish* means ‘to act fraudulently, fool, bluff’ (see Badawi & Hinds, *A Dictionary of Egyptian Arabic*, Librairie du Liban, 1996). Perhaps we can translate the name of our instrument as ‘the (device) based on a trick’?

can join them. Place the ruler on the divisions of the largest circle and at the centre, and mark (the intersection of) the side of the ruler (with) the arc. Place one leg of the compass at the centre and the other one on each of these divisions, and draw circular arcs going to the northern line. Then divide each of the arcs of Cancer, Capricorn and Aries into 180 (parts). Join the three marks with the compass, and write their arguments on them. In the north-eastern quadrant, there may be marked the sines. Write the values of the arcs of the quadrant on them, on the eastern line. This is the most basic part (?) of this instrument.

{*Diagram*}[2]

Diagram of the *mubakkash*, which has a nice shape.

<Text in the diagram:> Arcs of the excesses (of daylight) opposite to the sign (*jiha*) of the latitude. – Arcs of the excesses (of daylight) with the same sign as the latitude. – Capricorn, parallel of Aries, Cancer. – East, West.

<Remark:> This universal instrument works for all zodiacal signs from latitude zero to latitude 60°. From latitude 60° to 89°, it works only for certain zodiacal signs, and it is useless for the remaining ones. It has a thread (attached) at the centre.

33 *On the construction of the southern 'counterbalancing' astrolabe.*

p. 78 Trace a circle and divide it into four quadrants. Trace the three day-circles as you did before. From the southern table determined from the *Tables of Time-arc*, take the entry corresponding to each altitude circle, and mark it on the circles of Cancer and Capricorn, as well as Aries. Then join the three marks: these will be the arcs of the altitude circles. Number them. As for the azimuths, it is as previously (explained): leaving them out is much better (*aṣlaḥ*) <than constructing them>. It is better to determine (the azimuth) from the azimuthal circle previously mentioned or from the (scale on the) limb, (as described in) the chapter mentioned.

{*Diagram*}

Plate of the southern 'counterbalancing' astrolabe.

<Text in the diagram:> This design has been invented by the author of this book.

For the rete, trace a circle with the size of the largest of the circles on the plate – and divide it into four quadrants. Then open (the compass) to the quantity between the day-circle of Cancer and that of Capricorn along the quadrature line of the plate in direction of the suspensory apparatus and underneath it, and

[2] See Plate 16.

transfer the compass with this opening until you place it on the quadrature line of the rete. Trace a complete circle, which will be the ecliptic. It is necessary that it consists of two (concentric) circles. Place the ruler at the right ascension of each zodiacal sign and at the centre of the rete, and trace straight lines between the two arcs encompassing the names of the zodiacal signs.[1] Do the stars as before, using their declinations, right ascensions and the directions of their declinations. It is necessary that the northern stars be marked on the northern ecliptic and that the southern stars be marked on the southern ecliptic. Write their names on it.

{*Diagram*}

Rete of the southern 'counterbalancing' (astrolabe).

34 *On the construction of the scorpion astrolabe, related to the construction of its rete..*

Trace a circle and divide it into four quadrants. Trace the circles of the tropics and that of the equator as you did already. From the table (for the altitude circles) take the entry corresponding to each altitude circle at each of the three day-circle, and mark that quantity on each day-circle. Join the marks: these will be the arcs of the altitude circles, each one being in a direction different from the other. Number them. As for the azimuths, their omission is more exact and better than to determine the azimuth with the azimuthal circle, whose construction has already been mentioned,[1] or from the limb, from the forthcoming chapters of the treatise. *p. 78*

{*Diagram*}[2]

Plate of the scorpion astrolabe for latitude 36°.

<Text in the diagram:> It was invented by the author of this book.[3]

For the rete, you need to trace a circle – which is the largest of the circles on the plate – and divide it into four quadrants. Open the compass to the distance between the day-circle of Capricorn (taken in one half of the plate) and that of Cancer (taken in the other half): this opening (corresponds to) the ecliptic.[4] Place one leg of the compass on the largest circle of the rete (at its intersection with one of the diameters) and the other leg where it cuts the diameter. Hold

[1] Cf. note 9 on p. 246.

[1] Chapter 31.

[2] See Plate 3.

[3] **D** adds the eulogy "may God have mercy upon him", which means that this copy was made after the death of the author.

[4] The text has 'ecliptic pole'.

it fixed, and with the compass that is on the circle trace a semicircle from one (extremity) of the other diameter towards the other direction. Likewise make a semicircle similar to it < on the opposite side >. Trace an arc < inside the two (semicircles) > which will encompass the names of the zodiacal signs.[5] The stars (are to be constructed) as explained before only with their declinations and right ascensions. It is necessary that the scorpion-like shape be ensured by the star-(pointers).

{*Diagram*}

Rete of the scorpion (astrolabe).

35 *On the construction of the diverging (*mutadākhil mutakhālif*) astrolabe.*

p. 78 This (name) is related to the construction of the plate, because the altitude circles are inside the plate, and are diverging one to each other.

Trace a circle and divide it into four quadrants. Trace the three day-circles as you did before. From the table (for the altitude circles) take the entry corresponding to each altitude circle, and mark these quantities on each three day-circles. Join these marks: these will be the arcs of the altitude circles Do this between the horizons on the quadrature line, and number them. As for the azimuths, (their construction) is as before. It is better (to determine the azimuth) with the azimuthal circle or with the limb.

{*Diagram*}

Plate of the diverging (astrolabe) for latitude 36°.

< Text in the diagram: > This figure has been invented by the author of this book.

For the rete, trace a circle and divide it into four quadrants. Determine the location of the ecliptic pole. Place one leg of the compass on it, and trace a complete circle. Then (trace) a circle smaller than this to encompass the names of the zodiacal signs.[1] This will be the ecliptic. Write the names of the zodiacal signs and their opposite signs, each sign together with its opposite. Place the ruler at the centre and upon the right ascension of each zodiacal sign. Trace a straight line between these two circles, until the zodiacal signs are completed. The stars (are to be constructed) as before with their declinations and right ascensions. It is necessary that the northern ones, depending on their right ascensions in the signs, be written in black, and the southern ones with a different colour (*bi-l-ʿaks*).

{*Diagram*}

Rete of the diverging (astrolabe).

[5] Cf. note 9 on p. 246.

[1] Cf. note 9 on p. 246.

36 *On the construction of the fitting (*mutadākhil mutawāfiq*) astrolabe*.

This (name) is related to the construction of the plate, because the altitude circles are inside the plate and fit one to each other. Trace a circle and tracing the three day-circles as before. From the northern and southern (astrolabe) tables take the entry of the hour-angle corresponding to each altitude circle, and take its quantity for each of the three day-circles. < Mark the day-circles > and join these three marks (as circular arcs): these will be the arcs of the altitude circles. Connect them to each other. The azimuths, as we already mentioned, are best (determined) with the limb. *p. 78*

{*Diagram*}

Plate of the fitting (astrolabe) for latitude 36°.

< Text in the diagram: > This figure has been invented by the author of this book.

For the rete, trace a circle having the size of the largest circle of the plate. Then (trace) a circle smaller than this which will encompass the names of the zodiacal signs.[1] This will be the ecliptic. Place the ruler at the centre of the rete and upon the right ascension of each zodiacal sign, reckoned in parts of the largest circle. Trace a line between these two circles: the zodiacal signs are thus precisely delimited. Write their names and the names of their nadirs at a single place.

For the stars, place one leg of the compass at the centre of the plate and the other leg upon (the altitude circle corresponding to) its declination and direction, and transfer it (onto the rete) with that opening so that you can put < one leg > at the centre of the rete and the other one where it cuts the line of its degree of mediation: this will give you the location of the star. Write its name on it. It is necessary that all northern and southern stars be on this rete, whereas we have omitted < ... > (?) them at the right (?).

{*Diagram*}

Rete of the fitting (astrolabe).

37 *On the construction of the crescent astrolabe. This is the tenth of (those) we have invented.*

We would have invented more, if this would not have meant that the commentary would become too long. If their designs are drawn (combined) with the design of another of the same astrolabic kind (*li-jins al-muqanṭarāt*), then design of the plates is changed. I found this process to be endless. I have found the best of (all those) designs to be the northern and southern (astrolabes), both of which were mentioned in the first (two) chapters. For that *p. 78*

[1] Cf. note 9 on p. 246.

reason, I have restricted (my exposition of the non-standard astrolabes) to ten of them, in addition to those al-Bīrūnī presented (*waḍaʿahā*), namely, seventeen plates (*sic*: read astrolabes) and three well-known (instruments), namely, the spherical (astrolabe), the armillary sphere, and the ruler (astrolabe). Their total is thirty.

If you want to make this plate, (it is like) the construction of the 'southern counterbalancing' (plate) in Chapter 33. The exterior altitude circles at its centre (?) are the 'diverging' altitude circles, as in Chapter 35, excepts that they are complete in both eastern and western directions. Write their numbers on them. (The construction of) the azimuth is as before, or (you can also find it) from the limb.

{*Diagram*}

< Plate of the crescent astrolabe. >

For (the construction of) the rete, open the compass to the largest circle of the plate; place one leg < at the centre and the other leg > elsewhere. Trace a circle with (this) other leg and divide it into four quadrants. Again take an opening of the compass measuring the distance between the day-circles of Cancer and Capricorn on two of the lines of the plate, namely, (two lines) with two different directions. Transfer this (distance) with this opening so that you place it on one diameter of the rete, with (?) the largest circle, and (place) the other leg where it cuts the diameter. Trace a semicircle, which will be one half of the ecliptic belt. Transfer again this opening on the other diameter (!)[1] and trace a semicircle: this will be the other half of the ecliptic. Still better than what is made according to this description is: (the belt) is dispensed through one half of (its) largest semicircle from its entirety (??). Write the names of the zodiacal signs on each of them, like on the first and second ones. As for the stars, (they are to be constructed) as before with their declinations and directions, right ascensions or mediations.

{*Diagram*}

< Rete of the crescent astrolabe. >

38 *On the construction of the ruler astrolabe.*

p. 79 It is the northern (astrolabe) first (presented), which has the best of all shapes, and which is nearest to astronomical (truth) (*aqrabuhā ilā al-hayʾa*) and the best one in terms of methods (?) in the treatises (on their use?), despite the

[1] What is meant is the opposite radius of the same diameter.

fact that[1] some of these designs are difficult in their use (? *fī risālatihi*), and are <not> obvious to anyone who has no understanding of it in the manner of preparing their designs. Because of that, we started with it at the beginning of the presentation (*waḍʿ*) and we concluded with it at the end of it. This is the last one (*tamām*) of thirty astrolabes.[2] If you want to make it, just do what you did for the (usual) northern (astrolabe). There is no need to repeat its construction (here). Understand this and you will get it right.

Be aware that (for) each of these astrolabes whose construction has been mentioned, except the spherical one and the armillary sphere, as soon as you install this ruler on it, it will be called a ruler (astrolabe), else a thread makes the ruler superfluous. It is necessary to attach (lit. 'to draw') the star-(pointers) to the alidade, which moves over the face of the plate. If al-Bīrūnī had not mentioned it in his book, I would not have illustrated it here. Many plates, however, do not have a rete, only an alidade or a thread are mounted on them. When there is a thread, it is necessary that its stars be drawn on the plate, as (on) the solid astrolabe; the star-(pointers) are attached to (lit. 'drawn on') the alidade.

{*Diagram*}

The northern plate on the plate (*sic*) of the ruler (astrolabe).

To construct the alidade, open the compass to the radius of the plate. Then place one leg of the compass at the pole of the alidade, and mark the location of the other leg (on the alidade), in both directions. Open the compass to the meridian altitude of each zodiacal sign. Place one leg of the compass at the centre of the alidade and the other leg where it cuts the side of the alidade: this is the place (for the mark) of the zodiacal sign. The stars, (are to be constructed) as before using their declinations and right ascensions.

{*Diagram*}

<Alidade of the ruler astrolabe.>

39 *On the construction of the* shakkāziyya.[1]

We trace a circle and we divide it into four quadrants. We then determine for it a table from the *Tables of Time-arc*, for latitude 0° and at the equinox. But we find that the altitude coincides with the time-arc, so, for that reason, we leave *pp. 100, 109*

[1] Both manuscripts have بان , which can only be read as *bi-anna*, but I prefer to emend this as *maʿa anna*.

[2] The Arabic of this sentence is very poor, but the intended meaning must correspond to this translation. Concerning the total of 30 astrolabes, see Ch. 37.

[1] The contents of this chapter is virtually identical with the first half of Ch. 9.

out this table. We place the ruler at the pole of projection and on the argument of the altitude circle (measured on the outer rim). We mark its intersection with the ‘suspension line’. Then we place one leg of the compass on the north-south line, and we trace a semicircle with the other leg (which passes through the mark on the ‘suspension line’ and ends) on (each) graduation of the greatest circle – which is the day-circle of Aries. We continue this operation until the altitude circles are completed.

As for the azimuth (circles), place the compass on the line (passing at) the centre of the circle and intersecting the line of the north and south poles, and trace an arc going in both directions of the north-south line, (and repeat this operation) until the azimuth arcs are completed. This plate is for latitude 0°, perfect of its kind (? – *kāmila fī l-jins*).

For the longitude line, trace a line passing through the centre and the value of the inclination of the ecliptic (measured on the outer scale). Trace also the line of latitude, passing through the centre from the complement of the obliquity of the ecliptic. Write on one quadrature line the meridians from the beginning of the division of the circle, with the measure of the sphere, that is 360°. Take in terms of these parts the right ascension, beginning with Capricorn, and make a mark. Place one leg of the compass on the longitude line and the other leg upon these marks and upon the complement of the obliquity of the ecliptic, in both directions, that is the ecliptic poles, and with the other leg draw a circular arc that joins both extremities of the circle: these are the arcs of the zodiacal signs.

If you want, determine the two distances[2] of one altitude circle: take the tangent of half the altitude, to which you add two thirds of it. For each degree of the result, subtract one minute. Add one half of the result to it, and add to each degree of this sum one minute. This is what we look for. This table dispenses of the (geometrical) construction of this instrument, the *zarqālliyya*, the *musātira*, the *musattar* quadrant and the plate of the *shajjāriyya*; and likewise for the quadrant (versions) of these instruments just mentioned, provided the radius is 30.

{*Diagram*}

Diagram of the plate of the *shakkāziyya*, this instrument being universal.

TABLE T.3. <Table for constructing the *shakkāziyya*>

θ	6°	12	18	24	30	36	42	48
ρ	1;33	3;07	4;43	6;24	8;01	9;45	11;29	13;20
θ	54	60	66	72	78	84	90	
ρ	15;16	17;20	19;30	21;44	24;17	27;00	30;00	

[2] Text has ‘radii’.

This table is for (constructing) the meridian arcs of the (*shakkāziyya*) and (*zarqālliyya*), the altitude circles on the *musātira*, the radii (of astrolabes) for latitude 0°, and the radius (*sic*: read radii) of the *musattar* quadrant,[3] on the condition that the radius of the plate (on all these instruments) has 30 equal parts.

40 *On the construction of the* shakkāziyya *quadrant.*

Trace a circle and divide it into four quadrants, which you divide into 90 (equal) parts. Find from the tables the value of the time-arc at each 5°, or otherwise, for latitude 0°, at the equinoxes. We found that (in such cases) the altitude coincides with the time-arc, so, for that reason, we left out this table. We determined a table with the method of the radii, and this is the one mentioned before and here tabulated, in order to help us (in constructing) the *shakkāziyya* and *zarqālliyya* quadrants. We then divide one of the quadrature lines by the radius of the equator, that is $19;39^p$. We take in terms of these parts the entry corresponding to each altitude circle. Place one leg of the compass on that line and on each division of the quadrant, and trace an arc with the other leg: this will be the day-circle. Do this procedure again in the other direction, (with a leg of the compass) on the pole, and trace a circular arc, which will be the meridian. Repeat this operation until the quadrant is completed. Trace the longitude line from the centre to the value of the obliquity of the ecliptic. Number the arcs of the meridians on the quadrature line. Place one leg of the compass at the centre and the other leg on the right ascension of Aries. Move the (compass) until (it meets) the longitude line, and make a mark. (Do) the same for the ascensions of Taurus and Gemini, and write the names of the twelve zodiacal signs on the longitude line, forwards and backwards. pp. 111, 109

TABLE T.4. Table of the radii

θ	85	80	75	70	65	60	55	50	45
ρ	18;00	16;30	15;[7]	13;46	12;32	11;21	10;15	9;10	8;09
θ	40	35	30	25	20	15	10	5	
ρ	7;11	6;12	5;16	4;21	3;28	2;34	1;43	0;51	

{*Diagram*}

Diagram of the *shakkāziyya* quadrant.

41 *On the construction of the* zarqālliyya *quadrant.*

It is the superposition of two *shakkāziyya* quadrants, but the arcs of the first pp. 111, 109

[3] This statement is incorrect, unless the *musattar* is intended for a latitude 0°, in which case it becomes equivalent to a *shakkāzī* quadrant.

one do not coincide with the arcs of the other one. Trace a quarter circle bounded by two perpendicular radii. Divide it into 90 (equal) parts. Do what you already did with the *shakkāziyya* quadrant, and trace the declination arcs and the meridian arcs as before. Place the ruler at the centre and on the obliquity of the ecliptic, counting from the end of the outer scale,[1] and trace an invisible straight line of indeterminate length.[2] Place one leg of the compass at the centre and the other leg on the line of the divisions of the quadrant,[3] (with the opening) measuring the divisions of the day-circles. Hold its leg fixed at the centre while moving the other leg until (it meets) the straight line, and make the marks of the day-circles on it. Then transfer with this opening (of the compass) < the distance of > each five degree division of the outer scale < from its end > by placing the (other) leg at the point of intersection of the (imaginary) line with the outer scale. < Make a mark on it >. With the leg (of the compass) trace an arc to the left and to the right without going out of the quadrant. Then place one leg on the straight line (so that) the other leg (be) on both marks. Trace a circular arc intersecting both extremities of that arc. These will be the declination arcs of the *zarqālliyya*, which do not coincide with those of the *shakkāziyya*. The point < at the end > of this line will be the point of the ecliptic pole.

{*Diagram*}

Diagram of the *zarqālliyya* quadrant.

42 *On the construction of the spiral astrolabic quadrant.*

p. 85 Trace a quarter circle bounded by two perpendicular diameters. Divide the radius into 30 (parts), and from these parts take the radius of the equator as $19;39^p$. Place one leg of the compass at the centre and draw a circle, which will be the equatorial day-circle. Open (the compass) to the radius of one of the tropics, that is $12;54^p$, and do likewise (a circle), which will be the day-circle of one of the tropics, depending of the direction of the (terrestrial) latitude. Open (the compass) to the excess of equatorial revolution from the horizon (?) that is inscribed in the table already mentioned and with which you constructed the altitude circles, and place one leg of the compass on the meridian line at its intersection with the largest arc. With the other leg mark the arc of the largest circle. Place the ruler upon the hour-angle, reckoning from the end of the outer scale, and mark the equatorial day-circle and the

[1] Literally 'end of the quadrant', *passim*.

[2] Textually "an invisible infinite (*bi-ghayr nihāya*) straight line", which means in fact that the line should be extended in both directions as much as is physically possible on the sheet of paper or on the metallic plate. See also n. 1 on p. 254.

[3] I.e., the meridian line.

day-circle of one of both tropics. There results three marks: join them with a circular arc, which will be the arc of that altitude circle.

If you want the azimuth (circles), open (the compass) to the (value of the) entry in the table of the azimuth in terms of the distance from[1] the centre of the circle of first azimuth. Place one leg of the compass at the pole of projection and the other leg where it cuts the 'pivot line'. Trace a straight line: this will be the 'eastern line' of the circle of first azimuth. <... > Join them with the zenith point, as before. If you want, you can leave out (the azimuth markings). Then (the azimuth) will be known from the azimuthal quadrant, whose explanation will follow (in this book) after (the discussion of) the quadrants. (For) each (astrolabe) quadrant (which) is not provided with azimuth markings, (the azimuth) can be known with (the azimuthal quadrant). But it is better to determine the azimuth with the azimuthal quadrant, otherwise (the markings) are obscure (and confused).

{*Diagram*}

Diagram of the spiral (astrolabic) quadrant for latitude 36°.

43 *On the construction of the universal astrolabic quadrant.*[1]

Trace a quarter circle bounded by two perpendicular radii. Draw the day-circles of the equator and of Cancer. Divide the distance between the centre and the equator into $19;39^p$. From these parts, take the radius of each altitude circle from the *Table of the radii*,[2] and make the marks of the altitude circles. Place one leg of the compass at the centre and the other leg where it cuts the meridian line. Move the compass so that you can lay one of its legs on the meridian line and the other leg upon the mark of the altitude circle and upon its respective division on the outer scale. Join them as circular arcs by successive approximations, until all altitude circles are completed. *pp. 109, 111*

For the azimuth, place one leg of the compass at the centre and the other leg on each of the marks of the altitude circles (on the meridian line). Hold the first leg of the compass fixed at the centre, and move the other leg onto the east line (and make a mark there). When (the transfer of) the marks that are on the meridian line onto the east line is completed, place one leg of the compass on the east line[3] outside the quadrant (so that the other leg can be placed) upon each mark (you made) on it and upon the altitude circle for 90°.[4] Trace a circular arc to the 90° altitude circle. When the marks inside the equator are

[1] The text has 'of'.

[1] This chapter describes the construction of the quadrant version of the universal plate of Ibn Bāṣo described in Chapter 10.

[2] This is the table presented in Chapter 40.

[3] In fact this has to be on the western side of the quadrant.

[4] I.e., the 90° division on the outer scale.

completed, place one leg (of the compass) on the east line inside the quadrant (so that the other leg can be placed) upon each of the remaining marks and upon the point of (altitude) 90°. Trace circular arcs: these will be the azimuth arcs. Then, place one leg (of the compass) at the centre and the other leg upon each mark of the meridian line, and trace (concentric) arcs[5] from the meridian line to the east line. The construction is now completed.

{*Diagram*}

44 *On the construction of the counterbalancing astrolabic quadrant.*

p. 85 Trace a quarter circle bounded by two perpendicular radii. Draw the day-circles of equator and Cancer. Place the ruler upon the hour-angles for each altitude circle (taken) from the table that has been calculated for the construction of the altitude circles at the three day-circles. Mark this (quantity) on each day-circle and join these marks with the compass. If the day-circle of Capricorn – which is the largest – is complete, join the marks of equator and Cancer. And if the altitude circles at equator are complete, determine the hour-angle for the two stars mentioned in the table. Join these three marks with a circular arc. The first (set) of altitude circles reaching the outer scale is now completed. If you want the second (set) of altitude circles reaching the horizon, place one leg of the compass on the meridian (line) outside of the quadrant, and upon the altitude circle of the terrestrial latitude for which this (plate) is being constructed, at the intersection of the equatorial circle with the east line, and draw a circular arc from there to the meridian line: this will be the second horizon. Then move one leg (of the compass) until (it meets) the altitude circle that is underneath the horizon, at the intersection of this altitude circle with the day-circle of Cancer. Trace a circular arc (from there) to the meridian line. Do this (operation) until the altitude circles are completed. As for the azimuths, it is better to determine them with the azimuthal quadrant.

{*Diagram*}

Diagram of the counterbalancing astrolabic quadrant for latitude 36°.

45 *On the construction of the myrtle astrolabic quadrant, which is (also) the drum astrolabic quadrant.*

p. 85 Trace a quarter circle bounded by two perpendicular radii. Divide this quadrant into 90 (equal parts): this (outer scale) will represent the circle of one of either tropics. Draw the day-circle of the other one of the tropics and the equatorial one, as you did previously. Mark each of these three day-circles

[5] These are actually semicircles.

with the hour-angle inscribed for each argument of altitude in the table mentioned before and serving the construction of altitude circles. Place one leg of the compass on the meridian line,[1] and by successive approximations join these marks: these (arcs) will be the altitude circles open towards the meridian line.

If you want the altitude circles that are open towards the eastern line,[2] mark also the hour-angle, written in the table already mentioned, on the day-circle of the opposite degree of the ecliptic (*al-naẓīr*). When the marks of the three day-circles are completed, join them with a circular arc, until all of the altitude circles are completed. Number them. As for the azimuth (markings), leaving them out is more appropriate (than constructing them). It is better to determine the azimuth with the azimuthal quadrant, whose explanation will follow.

{*Diagram*}

Diagram of the myrtle quadrant, or drum quadrant, for latitude 36°.

46 *On the construction of the skiff astrolabic quadrant.*

Trace a quarter circle bounded by two perpendicular radii. Divide the outer scale into 90 (equal parts): this (arc) will represent the circle of one of both tropics. Draw the day-circle of the other tropic, as you did previously, and the equatorial one. Mark each of these three day-circles with the hour-angle inscribed for each argument of altitude in the table mentioned before and serving the construction of altitude circles. Place one leg of the compass on the meridian line, and by successive approximations join these marks, which are connected to the horizon. When the altitude circles are completed, inside the horizon and outside of it, connect the interior ones to each other and number them between the arcs of the altitude circles (or) wherever you wish, until all altitude circles are completed. As for the azimuth, it is as before: it is better to obtain it from the azimuthal quadrant, whose explanation will follow. *p. 85*

{*Diagram*}

Diagram of the skiff quadrant for latitude 36°.

47 *On the construction of the tortoise*[1] *astrolabic quadrant.*

Trace a quarter circle bounded by two perpendicular radii. Divide the outer scale into 90 (equal parts): this will represent the circle of one of the tropics. Draw the day-circle of the other tropic, and the equatorial one, as you did *p. 85*

[1] Literally 'line of the end of the quadrant', *passim*.
[2] Literally 'line of the beginning of the quadrant', *passim*.
[1] See p. 41 of the introduction.

previously. Mark each of these three day-circles with the hour-angle written in the table for each altitude argument and serving the construction of altitude circles. Place one leg of the compass on the meridian line, and join the three marks inside of the equatorial circle and outside of it. Connect them to each other and number them. Leaving out the azimuth (markings) is more appropriate (than constructing them). It is better to determine the azimuth with the azimuthal quadrant, whose explanation will follow.

{*Diagram*}

Diagram of the tortoise quadrant for latitude 36°.

48 *On the construction of the bull astrolabic quadrant.*

p. 85 Trace a quarter circle bounded by two perpendicular radii. Divide the outer scale into 90 (equal parts): this (arc) will represent the circle of one of both tropics. Draw the day-circle of the other tropic, and the equatorial one, as you did previously. Mark each of these three day-circles with the hour-angle written for each argument of altitude in the table mentioned before and serving the construction of altitude circles. Place one leg of the compass on the line of the centre that passes through the end of the outer scale, and join the three marks inside of the equatorial circle and outside of it. Connect them to each other and number them. Leaving out the azimuth (markings) is more appropriate (than constructing them). It is better to determine the azimuth with the azimuthal quadrant, whose explanation will follow.

{*Diagram*}

Diagram of the bull quadrant for latitude 36°.

49 *On the construction of the jar astrolabic quadrant.*

p. 86 Trace a quarter circle bounded by two perpendicular radii. Divide the outer scale into 90 (equal parts): this (arc) will represent the circle of one of both tropics. Draw the day-circle of the other tropic, and the equatorial one, as you did previously. Mark each of these three day-circles with the hour-angle written for each argument of altitude in the table mentioned before and serving the construction of altitude circles. Place one leg of the compass on the meridian line, and join the three marks inside and outside of the equatorial circle, each with the other, and then number them. Leaving out the azimuth (markings) is more appropriate (than constructing them). It is better to determine the azimuth with the azimuthal quadrant, which is (explained) right after this (one).

Be aware that these eight (astrolabic) quadrants here depicted do not resemble each other. We have left out the rest of them because of that, and their

designs do not differ from each other, except when (we are dealing with) a plate with a complete set of day-circles, but it is not possible to form a quadrant from them.[1]

{*Diagram*}

Diagram of the jar quadrant for latitude 36°.

Know that all of the quadrants whose construction has been mentioned are drawn without any excess (over) an (actual) quadrant (of markings), namely, there is no excess (*ziyāda*) to use (any of them).[2] I am not aware of anybody having mentioned the way to use it. Some people say that it is known by the method of the opposite degree of the ecliptic (*al-naẓīr*), but this is a big mistake, for this (affirmation) has no validity.

The method of determining the time-arc is only (as follows): When the thread goes off the quadrant, place a second bead on the thread at the intersection of the thread with the horizon. Then move the thread onto the meridian line, looking at the arguments of altitude circles on which the two beads fall, starting (to count) at the equatorial circle. Take this (quantity) in the other direction and move the thread so that you can place each of the two beads upon the horizon. Look how far the thread moves away from its position on the outer scale: This will be the time-arc for that altitude. And this can also be done with any astrolabic quadrant.

50 *On the construction of the azimuthal astrolabic quadrant.*

The quadrants whose constructions have been presented do not have the mark- *pp. 54, 57*
ings of the azimuths, because they were left out. We have therefore determined the azimuth with the tables and we have then constructed this quadrant. To make it, trace a quarter circle bounded by two perpendicular radii. Determine the time-arc from the table for each ten degree of azimuth, and mark its quantity on the outer scale (*sic*![1]). Open the compass to the distance of the zenith (from the centre) and place one leg of the compass on the line of < the end of > the quadrant and the other leg upon the zenith point. By successive approximations with the compass join both poles of projections with the zenith point. Hold the compass fixed on the eastern line of the azimuthal circle (*sic*![2]), and with the compass that is on the zenith point, trace a circular arc to the mark on the outer scale. This will be the arc of the azimuth. Do all of them and number them.

[1] The precise meaning of this paragraph eludes me.

[2] Actually, all astrolabic quadrants illustrated in Najm al-Dīn's treatise do feature the excess in question; only the *musattar* quadrant is restricted to a quadrant.

[1] This should be the equatorial semicircle. The same mistake occurs in Ch. 31.

[2] This should read: 'eastern line of the prime vertical'.

These markings are placed on the back of each quadrant whose construction has been mentioned, when the azimuth is not being determined from the outer scale.

{*Diagram*}

Diagram of the azimuthal quadrant for latitude 36°.

<Remark:> This quadrant needs to be placed at the back of each of the astrolabic quadrant mentioned above, when the azimuth is not being determined from the outer scale.

51 *On the construction of the seasonal and equal hours (on astrolabic plates).*

p. 58 On the (astrolabic) plates whose constructions have been mentioned, there are no hour-lines. It would have been burdensome to us to have illustrated them to complete the construction of all the instruments.

If you want (to construct such hour-lines), trace a circle and divide it into four quadrants. Draw as before the three day-circles, and determine the altitude of (each) seasonal and equal hour, for each day-circle. Place one leg of the compass on the rising-point of Aries, <Capricorn and Cancer,>[1] and the other leg on that altitude. Move (the compass) with this opening so that you can lay it at the horizon upon the rising and setting points of (that) degree of the ecliptic. < ··· >[2] Once you have placed the marks on the three day-circles, join them as circular arcs, which will be the seasonal and equal hour-lines. Their total extent (*futḥatuhā*) is the same as that of the horizon.[3]

{*Diagram*}

Plate of the hours for latitude 36°.

<Text in the diagram:> First, second, . . . , twelfth (hour). – The seasonal hours are in red and the equal ones in black.

52 *On the construction of the equal hours with another method.*

p. 58 Trace a circle and divide it into four quadrants. Draw the circles of the equator and of Cancer. Determine the altitude corresponding to each 15° of the time-arc from the *Tables of Time-arc*, as before, for each of the (three) day-circles.

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[1] Compare Ch. 52.

[2] Here the text omits to explain how to mark the day-circles below the horizon. This is mentioned in Ch. 52, but in a very garbled way.

[3] I.e., the sum of the angular distances between each hour-lines (for a particular declination) is the same as the angular distance between the rising and setting points – which corresponds to the total daylight on that day.

Place one leg of the compass upon the rising-points of Aries, Capricorn and Cancer, and the other leg on the altitude circle corresponding to the parts (ecliptic degree) of this hour. Move the compass with this opening so that you can lay it on the horizon at the rising- and setting-points of (that) degree of the ecliptic, and mark the day-circle of that point of the ecliptic with the other leg.[1] Once you have placed the marks on the three day-circles, join them (to form) circular arcs from the horizon to the circle of Capricorn, which is the largest one.

Know that the extent (*fuṭha*) of the arc of the horizon is the extent of the hour-lines, and you do not have to change the opening of the compass (on each of the three day-circles).

{*Diagram*}

Diagram of the equal hours, on their own. Plate of the hours for latitude 36°.

53 *On the construction of the diurnal* musātira.

Trace a circle and divide it into four quadrants. Take the rising amplitude of the solar longitude in the table compiled using the *Tables of Time-arc* already mentioned. Enter this on the (circumference of) the largest circle, and make a mark on each of the eastern and the western sides. Place the ruler on the argument of the altitude circle upon the outer scale, starting from the suspensory apparatus, and at the beginning of the scale of the (opposite) quadrant. Mark the <intersection> of the side of the ruler with the 'suspension line'. <Continue to do this> until the <marks of the> altitude circles are completed. Count the meridian altitude (corresponding to) the solar longitude along the <marks of the> altitude circles, starting from the southern point <and make a mark>.[1] Place one leg (of the compass) on the 'pivot line', and do successive approximations with the compass until you can join the mark of the meridian altitude and the two marks of the rising and setting amplitudes with a circular arc, (which reaches) the right- and left-hand sides of the circle: this will be the day-circle of that zodiacal sign. Once the (day-circles of each) zodiacal sign are completed, write their names on them. *p. 87*

[1] This is incorrect: the compass should in fact be placed at the intersection of the horizon with the day-circle of opposite declination (in the case of the tropics), and the mark should be made on this day-circle below the horizon.

[1] It would be in fact more accurate to do these marks in the same way as those for the altitude circles, by placing the ruler on the pole of projection and on the graduation of the meridian altitude on the outer scale, and then by marking the intersection of the ruler with the meridian line, instead of interpolating visually between the marks for the altitude circles.

Make a mark at the 'zenith' (!)[2] and place one leg of the compass on the 'suspension line'. By successive approximations with the compass, join both poles of projection with the 'zenith', and draw a circular arc from the day-circle of Cancer to the pole of projection, on each of the left- and right- hand sides, (terminating) on the circumference (*qaws*) of the circle.[3]

If you want the altitude circles, place one leg of the compass at the centre and the other leg upon the mark of each altitude circle, and draw a circular arc from the day-circle of Capricorn to the day-circle of Cancer. (These altitude circles) may (also) be placed on the alidade.

If you want the (arcs of) hour-angle[4] find from the table the altitude corresponding to each 5°, or otherwise, of the hour-angle.[5] With these values for the (respective) altitude circles, mark the three day-circles. Place one leg of the compass on the 'prime arc of the hour-angle' (*qaws awwal* [*faḍl*] *al-dāʾir*)[6] and the other leg on the three marks. Join them by successive approximations, and draw a circular arc from the day-circles of Cancer to that of Capricorn, or from the day-circle of Cancer to the circumference of the circle.

< The construction > is completed.

{*Diagram*}[7]

Diagram of the diurnal *musātira* for latitude 36°.

54 *On the construction of the nocturnal* musātira.

p. 87 Trace a circle and divide it into four quadrants. Do as you did for the diurnal (*musātira*), except that you should take for each altitude circle the values of the rising and setting amplitudes from the table represented on this page. Proceed as you did already with the rising amplitude of the zodiacal signs. When the marks of the rising (and setting) amplitude for each declination are completed, < put the ruler on the pole of projection and on the graduation of the outer scale (of the opposite quadrant) that corresponds to the meridian altitude (corresponding to) each arc of declination, and mark the intersection of

2 Instead of designating the centre of the plate, which on this instrument represents the real zenith, this 'zenith' rather refers to the projection of the *northern celestial pole*. In Ch. 54 it is correctly designed as *quṭb muʿaddil al-nahār*.

3 These two circular arcs represent an hour-angle of 90°. This paragraph should logically occur later, since it deals with a special case of the markings for the hour-angle, whose construction is explained in the last paragraph.

4 Text has 'time-arc', *passim*.

5 The table in Ch. 4 is the only one in the treatise that can possibly be implied here. However, it contains entries of $h(T)$ instead of $h(t)$, which makes impossible the construction of the markings at the solstices. See the commentary for further details.

6 I.e., the projection of the great circle corresponding to an hour-angle of 90°. This term is used by analogy with the expression for the prime vertical: *qaws* (or *dāʾirat*) *awwal al-sumūt*, lit. 'arc (or circle) of the beginning of the azimuth'.

7 See Plate 4.

the side of ruler with the meridian line. > Join (these marks) to form the arcs of declination (*madārāt*) in the same manner as you did those (corresponding to) the zodiacal signs on the diurnal (*musātira*), until the arcs of declination of this *musātira* have been completed up to 180° (*sic*).[1] Number them. Once the day-circles of the rising and setting amplitudes are completed,[2] mark the value of the lowest and highest altitudes[3] on the 'suspension line' (*sic*: read 'pivot line'). (Each pair of marks giving you the extremities of a diameter), trace complete circles. The day-circles are thus completed.

If you want the (arcs of) hour-angle,[4] join the two poles of projection with the (north) celestial pole (*quṭb muʿaddil al-nahār*), and trace a circular arc reaching the circumference[5] of the largest circle: this will be the 'prime arc of the hour-angle'. Trace the east (-west) line of that arc.[6] From the table of the altitude circles already mentioned, find the altitude corresponding to each 10° of the azimuth (*sic*: read 'hour-angle'), at the equinox.[7] Then place one leg of the compass at the centre and the other leg on the altitude circle (corresponding to the altitude found with the table). Move this leg until (it meets) the arc of the equatorial circle, and make a mark with this leg. Move (the compass) so that you can lay one leg on the 'east (-west) line of the prime circle of the hour-angle' and the (other) leg upon each mark (i.e., the north pole and the mark made on the equatorial circle). Draw circular arcs that reach the circumference[8] of the (outer) circle, and (passing through) the celestial pole, on which the terrestrial latitude is written. These will be the arcs of hour-angle. Do this operation in both the left and right directions, until the equatorial marks are completed.

Determine a circle among the circles of lowest and highest altitudes (?), and place one leg (of the compass) at the intersection of the 'prime arc of the hour-angle' with this circle, and the other leg upon the arc of hour-angle, at its

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[1] The upper limit for the day-circles where rising and setting are defined is in fact $90° - \phi$. Perhaps this results from a confusion with the arcs of hour-angle, which are numbered 6, 12, …180. On Najm al-Dīn's nocturnal *musātira* (for latitude 36°) the arcs of declination are numbered with their corresponding meridian altitude (4°–54° for southern declinations, and 64°–84°, 86°–36° for northern ones, plus the minimal altitudes 26°–6° for circumpolar declinations).

[2] This expression makes little sense; better would be: 'once the day-circles for which rising and setting amplitude are defined have been completed'.

[3] These are given in the table for declinations 60°–90°, where rising or setting does not occur.

[4] The text has 'time-arc', *passim*. This emendation is suggested by the illustration in **P**, which clearly displays the hour-angle.

[5] Literally 'the two sides' (*ṭarafay*).

[6] I.e., the east-west diameter of the 'prime circle of the hour-angle', which is perpendicular to the meridian. This is exactly similar to the 'east-west line of the prime vertical' which serves in the construction of the azimuth circles on an astrolabic plate.

[7] The entries of $h(T)$ in the column for Aries of the table in Ch. 4 would serve the purpose, since at the equinox the time-arc is the complement of the hour-angle. See the commentary for further details.

[8] Literally 'the two sides'.

day-circle (?). Move (the compass) with this opening until (it meets) this (arc of) hour-angle (? *ʿalā dhālika al-dāʾir*) in the other direction, and make marks that you join as you did already. The arcs of hour-angle are thus completed. Number them.

{*Diagram*}

Diagram of the nocturnal *musātira* for latitude 36°.

TABLE T.5. Table for constructing the (nocturnal) *musātira* for latitude 36°

Δ	ψ	Δ	h_m	η
10	12;23	60	66	6
20	25;00	70	56	16
30	37;39	80	46	26
40	51;58	90	36	36
50	70;24			

If you want, you do not need (to use) this table: the first table is actually sufficient.

55 *On the construction of the* musattar *quadrant.*

p. 87 This consists in the superposition of northern and southern altitude circles. If you want to construct it, (you should know that) it is exactly the same as constructing a northern and a southern astrolabic quadrant, except that the outer scale now represents the day-circle of the equator. If you want, mark on this arc[1] the rising amplitude for the declination written in the table.[2]

Then trace an imaginary (quarter) circle, and mark on it the time-arc that corresponds to this particular declination. Place the compass on the line of the quadrant and by successive approximations try to join the marks of Aries and Cancer. Be aware that the rising amplitude of the declination represents the time-arc of the (meridian) altitude of Aries. If you wish to construct it with the table, you do not need to (determine) the rising amplitude; make (it) with the first table (in Ch. 1) or (with) the table of the rising amplitude for latitude 36°. Once the marks of Cancer are completed, do the northern altitude circles as you did before, and join the marks of these altitude circles, holding the compass fixed on the meridian line. The altitude circles are thus completed. If some of the southern ones are not completed, join the rest of the marks of the rising amplitude with those of the northern altitude circles, and number them. In the same way, number the outer scale up to 90°. This quadrant is the

[1] I.e., the outer scale of the quadrant.

[2] Namely, the table in the previous Chapter. The only possible interpretation of this sentence is that Najm al-Dīn constructs the altitude circles on the *musattar* as if they were declination circles on the nocturnal *musātira*, which is indeed correct.

best of the (astrolabic) quadrants for specific latitudes: it does not require anything else, and there are no day-circles marked on it for inverting the northern (marks) into southern ones and the southern (marks) into northern ones, as we mentioned for the construction of (other kinds of) quadrants.

{*Diagram*}

Diagram of the *musattar* quadrant for latitude 36°.

< Remark in a different hand in **D**: > This entire arc has 90 divisions, but the person who drew (this illustration) has simply made a mistake. His ignorance is very considerable, (since) this is a (serious) mistake.[3]

56 *On the construction of the quadrant with harp markings (*al-rubʿ al-mujannak*).*

Trace a quarter circle bounded by two perpendicular radii. Between them trace the lines of the sines and cosines, counting the length of a radius as 60 (parts).[1] In terms of these parts, open (the compass) to the < cosine of the > half excess (of daylight) at one of the solstices. Place one leg of the compass at the centre (of the quadrant) and the other one below the centre, so that the total distance (measured from the beginning of the vertical scale[2]) be equal to the < versed sine of the > maximal half arc of daylight. Then place one leg at the end of the outer scale[3] and the other one upon the versed sine of the half arc (of daylight) for Cancer, and move (this second leg) until (it intersects) the line of the sine (i.e., the horizontal line) that corresponds to the sine of the meridian altitude at the beginning of Cancer.[4] Do the same (operation) for the beginnings of Leo, Virgo and Libra, and mark the appropriate positions on each of these day-lines. Trace straight lines (from these marks) to the point[5] at the end of the outer scale. Make (those markings) in such a way that there are four day-lines. The first one is for the two solstices, the second one for the equinoxes, the third one for each zodiacal sign whose declination is 11;32°, and the fourth one for each zodiacal sign whose declination is 20;16°. Write *p. 215*

[3] The scale in **D** is indeed divided into 90 parts from 0° to 60°, whereas the scale in **P** is divided as on a usual quadrant.

[1] The illustration in **P** is more explicit: these ‘lines of the sines and cosines’ form in fact an equidistant orthogonal grid; the lines are drawn for each 5 parts of the radii. There is a scale along the vertical radius which is graduated *downwards*.

[2] The text is once again very elliptic: this scale is not mentioned but it appears on the illustration – cf the above footnote.

[3] Literally ‘arc (of the quadrant)’.

[4] The text is not completely clear. This horizontal line has to be found according to the sine of the meridian altitude *read on the vertical scale*, which is graduated from the end of the outer scale to the centre of the quadrant.

[5] The text has ‘centre’ (!).

the corresponding signs of the zodiac along each day-line. Place one leg of the compass on the point at the end of the outer scale and the other one at the appropriate point (i.e., at the intersection of each horizontal line with the vertical radius) and trace a circular arc going to the marks of the sine: these arcs will meet the lines of the sines, if you want, at each 5°, or each 6° or at each degree, which is the best construction.

If you want, make it a (true) quadrant, without the extension of the half excesses (of daylight), but (in this case) make on it the 'horizon arc',[6], that is, place one leg of the compass on (the prolongation of) the line of the sexagesimal sine underneath the centre, and the other one where (each) day-line intersects (the line of) the sine of its (corresponding) meridian altitude, and upon the value of half excess in terms of a sine counted from the centre of the quadrant. Trace with one leg (of the compass) a circular arc to the line of the sexagesimal sine.[7]

The construction is completed.

{*Diagram*}

Diagram of the quadrant with harp markings for latitude 36°.

57 *On the construction of the universal horary quadrant (*al-sāʿāt al-āfāqiyya*).*

p. 214 Trace a quarter circle bounded by two perpendicular radii. Divide the quadrant into 90 equal parts. Place one leg of the compass on the meridian line, and by trying different openings of the compass, join the pole with the value for that (first) hour, which is 15, and so on until the six hours are completed. Do the same for the parts of the hours, be they at each 5° or each 3°, and write the arguments between the hour arcs. This is the principle underlying certain (construction) procedures. But if you do not want to trace the hour-lines by successive approximations, open (the compass) to the whole diameter, that is, 120 (parts), for the first (hour-line); to the radius, 60, for the second (hour-line); to half the chord of a quadrant, 42;25, for the third (hour-line); to the chord of one fifth of a quadrant, 37;4, for the fourth (hour-line); to the chord of one sixth of a quadrant, 31;4, for the fifth (hour-line); and to a quarter of the diameter, 30, for the sixth one.[1] Trace circular arcs with all of these specific openings (of the compass), from the value of the hour to the centre of the quadrant.

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[6] This might be an analogy with the folded horizon on the *musattar* quadrant – see the preceding chapter.

[7] The instructions are quite confused here, but the operation clearly consists in drawing the mirror image, with respect to the horizontal radius, of those portions of the circular arcs which would normally exceed underneath the horizontal radius, as if these markings were folded up – cf. Figure 5.12 on page 220.

[1] These numerical values are analysed on p. 5.2 of the commentary.

This horary quadrant, if you have done (the construction) as indicated above, without adding any more line or arc, will be universal. (It will serve) for all inhabited horizons, (i.e., for) the seven climates, between latitudes 0° and 48°, and for (timekeeping with) the sun, with a very good approximation. It is not possible to use universal horary quadrants which are designed for all inhabited or uninhabited locations for (timekeeping by) the sun or the stars, except when something else (is marked) on them, either trigonometric (markings) or numerical (data) (*immā min jins al-jayb aw min jins al-ḥisāb*). I have found that (such additional markings) on their own are superfluous for anyone who wants to use (the basic instrument). A chapter on it(s use) containing the procedures by approximate methods will follow.[2]

{*Diagram*}

Universal seasonal hours.

58 *On the construction of the sine quadrant.*

This is the most noble and the best of the universal quadrants, and the closest to the astronomical (truth) (*aqrabuhā ilā 'l-hay'a*)[1], and it is the 'seal' (i.e., the *nec plus ultra*) of the quadrants for operations (of spherical astronomy). *p. 210*

If you want to do this, trace a quarter circle which you divide into 90 equal parts. Divide the eastern line into 60 equal parts. Then get from the sine table the values of the sines at each 5°, or otherwise, and take these (values) in terms of those (60) parts. Place the ruler on this (value) on upon the arc of that sine, and trace a straight line going up to the outer scale: these will be (the lines of) the sines. Then place one leg of the compass at the centre of the quadrant and the other one on each part of the sines. Rotate the leg (of the compass) until (it meets) the (other) line and make marks (there). (From these marks) trace straight lines to the outer scale: these will be the (lines of the) cosines.

If you want to proceed by geometry, place one leg of the compass at the centre and divide the horizontal radius in two halves. Trace a quarter circle. Place the ruler at the centre and upon each division of the outer scale. Trace radial lines (from the centre) to that arc. When the radial lines are completed, place one leg of the compass at the intersection of that circle with the radial line, and with the other leg make marks on both sides. When the marks are completed, place the ruler upon each of them and on each 5° (division) of the outer scale, and trace straight lines to the outer scale, at the left and at the right. Thus, the sines and cosines are completed.[2] Understand this and you will get it right.

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[2] If such a chapter indeed existed, it must have belonged to another treatise.

[1] Cf. Ch. 38.

[2] This passage about a geometrical procedure for drawing the lines of the sine and cosine is extremely confused.

{*Diagram*}

Diagram of the sine quadrant.

59 *On the construction of the (instrument) with the two branches.*

p. 221 This is an observational instrument, especially (used) in this time of ours. The observational instruments like the armillary sphere and other instruments of the Ancients are expensive, but they nevertheless (?) require zeal and capability. This instrument is inexpensive and has few markings (on it). It has nothing but divisions on one of its sides, and the other (side) may be raised and lowered in the manner of compass. There may be legs and screws that are fitted to it. And one of its sides may be divided for each minute in order to measure the altitude. Since (the operations described) in this book of ours cannot dispense with the altitude, I have made it based on the meridian altitude. Indeed, we needed an exact instrument for measuring the altitude to (a precision of) one minute, and we have not found anything more suitable (for that purpose) that this.

If you want to construct it, take two flat rectangular blocks of wood set at right angles (to each other), so that their maximal opening measures the Chord of a quarter circle. We have installed (?) on it the divisions of the Chord, which is approximately 84;50[1], in order to measure the altitude with it. We then divided one of the stabs by the greatest sine, corresponding to the arc of a quadrant, also for measuring the altitude. Two sights are fitted on it, like on the alidade, for letting the shadow enter. When the shadow falls (on it), we have to check where the thread of the plumb-line is falling on the fixed side: this will give[2] the altitude. If we want, we can stick the side of the Chord (scale) to both extremities of the instrument. The (Chord) cut by its edge will give[3] the instantaneous altitude at this (particular) time.

{*Diagram*}

<Text in the diagram:> Aspect of the block which can move like a compass. – This is its greatest extent, the (instantaneous) altitude being 90°. – The plumb-line when the altitude is 90°. – Aspect of the plumb-line thread when the altitude is 60°. – The plumb-line when the altitude is 60°. – Aspect of the diametral block.

60 *On the construction of the* dastūr.

p. 210 Draw a circle and divide it into four quadrants. Divide the circle in 360 parts, each quadrant having 90 equal parts. I take the circle to be the equatorial

1 $\mathrm{Chd}_{60}(90°) = 120\sin(45°) = 84;51$ [error -1]
2 Literally 'will be'.
3 Literally 'will be'.

circle, for latitude zero. (In the time-arc table) I took the time-arc for each 5° of the altitude argument and I found it to coincide with the altitude. (Thus) I trace (the corresponding markings) as straight lines. All of them will fall upon the diameters: these will be the (line of) sines and cosines. I only wanted (to explain) the construction of this instrument in this book of ours because it is an old and noble one — may God have mercy upon the person who made it! And it renders superfluous calculation for anyone who has no skill in matters of multiplication and division. It is closer to the truth than other (instruments).

Anyone who wants to examine what we have mentioned about the tables and the construction, and who has no skill nor faculty in (the use of) the proportion tables (we have) mentioned at the beginning, for him this instrument is (most appropriate). This brings close to him everything he wants to find, especially if it is (made from) a large circle, and this is its picture. Anyone who makes additions to this construction does much more than is necessary, and makes it confusing. It is, however, necessary that an alidade with a sexagesimal division be fitted to it.

{*Diagram*}

<Diagram of the *dastūr*.>

<Text in the diagram:> The north-eastern quadrant. – The north-western quadrant. – The south-western quadrant. – The south-eastern quadrant.

61 *On the construction of the (universal) sundial based on the midday shadow, for (timekeeping with) the sun, and for those terrestrial latitudes contained in the seven inhabited climates, from latitude zero to latitude 48°.*

I have invented it for using versed sines and sines, and I have found in this *p. 164*
only a slight approximation. I then chose to include it in this book of mine because of the considerable difficulty of (constructing) sundials (*al-sāʿāt*) by means of versed sines, which compels us to change (the markings) for each latitude and write (the latitude) on each diagram. Then the explanations for that would be long. When we saw that these horary markings only display a slight approximation (if we use a universal procedure) and their utility would be of a great generality, I have expressed this meridian altitude in terms of midday shadows (taken) from the shadow table calculated for each minute (*min jadwal al-ẓill al-maḥlūl*).[1]

We determined the altitude of the hours from the horary quadrant described in Chapter 57 or by calculation (using an) approximate (procedure). (For that) you take the sine of the meridian altitude. Then take a quarter of it: this will be the sine of the altitude of the first (hour). Half the sine of the

[1] This refers to Najm al-Dīn's cotangent table, appended to the *Jadāwil al-dāʾir* (**B**:167r–173v), which is tabulated for each minute of argument.

meridian altitude will be the sine of the altitude of the second (hour). Half the sine of the meridian altitude and a fifth will be the sine of the altitude of the third (hour). Two thirds of the sine of the meridian altitude and a fifth will be the sine of the altitude of the fourth (hour). Finally subtract from the sine of the meridian altitude one third of one tenth thereof: this will be the sine of the altitude of the fifth (hour). You (also) add twelve to the midday shadow, and this gives you the shadow length at the *ʿaṣr*. Find the arc corresponding to the sine of the altitude of the hours: these are the required altitudes. Enter the altitude of the two (kinds of hours ?) in the shadow table and take the value facing it in terms of degrees and minutes: this is the shadow of (the altitude of) that hour. We have compiled for that purpose this table, (intended) for anyone who wishes to construct this sundial we have just described.[2] Understand this and you will get it right.

TABLE T.6. Table of the altitude of the hours from latitude zero to latitude 48°, by approximation, and for (timekeeping with) the sun. This (table serves) to make the marks on the 'locust's leg'.

m	1	2	3	4	5	6	*ʿaṣr*
0	15;00	30;00	45;00	60;00	75;00	90;00	45;00
2	13;47	29;33	43;41	58;56	72;33	80;36	40;37
4	13;30	28;28	41;39	55;02	66;31	71;34	36;51
6	12;51	26;28	38;36	50;33	59;49	63;24	33;41
8	11;54	24;33	35;30	46;10	53;34	56;24	30;55
10	11;00	22;32	32;27	40;53	47;55	50;10	28;37
12	10;09	20;42	29;38	37;47	43;06	45;00	26;34
14	9;22	19;00	27;06	34;21	38;35	40;37	24;47
16	8;38	17;28	24;48	31;20	35;27	36;52	23;14
18	7;58	16;06	22;30	28;56	32;25	33;41	21;47
20	7;23	14;58	21;04	26;27	29;47	30;56	20;32
22	6;54	13;50	19;40	24;31	27;40	28;37	19;26
24	6;25	12;55	18;18	22;45	25;38	26;34	18;26
26	5;56	12;00	17;05	21;18	23;47	24;47	17;32
28	5;34	11;13	16;00	19;58	22;03	23;14	16;41
30	5;21	10;30	15;00	18;48	21;02	21;47	15;56
32	5;02	9;52	14;56	17;44	19;50	20;32	15;16
34	4;46	9;20	13;30	16;46	18;46	19;26	14;36
36	4;35	8;50	12;45	15;54	17;30	18;27	14;02

[2] In fact, the sundial is described below!

TABLE T.7. Table of the shadow of the hours from latitude zero to latitude 48°, by approximation, and for (timekeeping with) the sun. These are the (shadows) on which (the instruments of the category) *mīzān* are based

m	1	2	3	4	5	*ʿaṣr*
0	44;47	20;47	12;00	6;56	3;13	12
2	48;55	21;10	12;34	7;14	3;46	14
4	49;55	22;07	13;34	8;24	5;13	16
6	52;35	24;05	15;00	9;51	6;59	18
8	56;58	26;18	16;46	11;31	8;51	20
10	61;44	28;53	18;50	13;52	10;50	22
12	67;01	31;42	21;05	14;25	12;49	24
14	72;47	34;53	23;28	17;34	15;02	26
16	79;05	38;10	26;00	19;44	16;50	28
18	85;45	41;33	28;56	21;55	18;53	30
20	92;41	44;53	31;08	24;07	20;56	32
22	99;45	48;31	33;33	26;20	22;54	34
24	106;49	52;19	36;17	28;33	25;00	36
26	115;31	56;28	39;03	30;46	27;14	38
28	123;12	60;33	41;51	33;00	29;40	40
30	128;19	64;08	44;47	35;06	31;12	42
32	136;16	68;58	44;54	37;36	33;13	44
34	144;05	73;09	50;00	39;48	35;21	46
36	149;41	77;10	53;00	42;05	38;05	48

If you want to construct these seasonal hours (on a universal sundial), take a board of wood or marble. Trace two thirds of a (complete) circle and divide (this circle) in four by two diameters, the first one (i.e., the vertical one) intersecting the arc in two halves and the other one cutting this line at (right) angles at the centre. Join the extremities of that arc with the centre (by means of a circular arc[3]): this will be the day-line for latitude 0° (!).[4] From the shadow table (in this chapter) take the argument corresponding to a (midday) shadow of zero in terms of the sine (!) of the first (hour): keep this in mind. Divide the radius of the circle by the longest shadow of that (first) hour which you want to enter on the sundial.[5] Take twelve parts of that amount: this will be the gnomon length, so consider it to be (your construction) scale. Take the shadow of the hour which you first kept in mind in terms of the divisions of the

[3] The text is far from being clear, but the illustration tells us that the sundial has the form of a lunule, that this arc will have the same radius as the basic circle, and that and its centre corresponds to its lower extremity.

[4] This corresponds in fact to a midday shadow of zero, which can occur only at subtropical latitudes. A latitude of 0° is the minimal positive latitude where this can occur.

[5] I.e., the shadow corresponding to the radius of the basic circle.

scale and place one leg of the compass at the centre and the other one where it intersects the day-line for latitude 0° (!): this will be the mark for that hour. Join it to (the corresponding mark on) the day-line for a meridian shadow of 36 parts: this is the day-line of the last of the inhabited latitudes, which is 48°.[6] Open (the compass) to the shadow of the remaining hours. Place one leg of the compass at the centre, the other one where it intersects each of both day-lines, that is, the first and last day-lines. These are the desired hours. If it is impossible to lay the first hour upon the day-line corresponding to a midday shadow of 36, then determine it for a day-line for which the shadow can still fall within the border of this circle. This way the seasonal hours have been completed. As for the equal hours, it is not possible to trace them in terms of midday shadows.

For the day-lines, open the compass to the radius and place one leg at the intersection of the meridian line with the (basic) circle, and make a mark with the other leg on (the circumference of) the circle, on both sides. (Join these two marks with a straight line:) this will be the smaller day-line, corresponding to a midday shadow of 36 (parts).[7] Divide (the space) between the larger day-line and the smaller one in two halves and trace a straight line, which will be the intermediate day-line, corresponding to a midday shadow of 18 (parts). Next divide (the space) between the intermediate day-line and the smaller one into three equal parts: there will be two day-lines, the first one for a midday shadow of 30 and the other one for a midday shadow of 24. Then divide (the space) between the intermediate day-line and the larger one into six equal parts. Counting three (![8]) of these six parts from the side of the intermediate day-line, you will get the day-line for a midday shadow of twelve (digits). Counting five (![9]) of these six parts from the side of the intermediate day-line, you will get the day-line for a midday shadow of 6 fingers. Place one leg of the compass on the meridian line, and proceed by successive approximations until you can join the two marks of all these day-lines, their midday shadow being (represented as) a circular arc. This is what we sought.

{*Diagram*}[10]

Diagram of the approximate universal horizontal sundial, for all inhabited latitudes from zero to 48°.

<Remark:> And if you want the arc of the *ʿaṣr*, open the compass to its (horizontal) shadow and place (one leg) on the centre and the other one on the day-line of (that) midday shadow, and join (the resulting marks) as a circular arc. God knows best.

[6] A midday shadow of 36 corresponds to $h_m = \text{arcCot}(36/12) = 18.43°$, and the minimal latitude with such a meridian altitude is indeed $\phi = 90° - 18.43° + \varepsilon \approx 48°$.

[7] The above construction appears to imply that the radius has 76 parts.

[8] Correct would be two.

[9] Correct would be four.

[10] See Plate 12.

62 *On the construction of the seasonal hours based on midday shadows, by another method.*

These are the hour markings that are made on the side of the *Fazārī* balance, *p. 163* because the day-lines corresponding to the midday shadow are straight (lines).

We want to distinguish their markings from the previous ones. This is of the nicest design, because if you do not/cannot determine the direction and do not distinguish whether the day-line is straight or curvilinear, < ··· > (?) but if it is indeed straight, that day-line is then better than if it were curvilinear. From that (instrument) whose construction has been mentioned, the hours can be known, but it is not possible to know the direction from it: the direction is for a particular latitude and this is only for the sun and for all inhabited latitudes with a slight approximation.

If you want that, divide the width of the marble plate – or anything similar – in two halves and trace a straight line, which will be the meridian line. Divide it into 36 segments: this is the (length) of the largest midday shadow that is tabulated. Let this define a (shadow) scale. Trace (these divisions) as straight lines. From the table of the shadow of the hours, take the amount of (each) hour and place one leg of the compass at the 'centre'[1] and the other one on the day-line for which you took its shadow, and make a mark on it with the other leg, at the left and at the right. When the marks of the hours are completed, join them and write on each hour its number and on each day-line the (corresponding) midday shadow that you found. The day-lines are thus completed. If you want (to draw) the arc of the *ʿaṣr*, open the compass to its horizontal shadow and place one leg of the compass at the centre and the other one where it cuts the day-lines of the (various) midday shadow(s), and join (these marks) as a circular arc.

{*Diagram*}

Diagram of the universal horizontal sundial, for all inhabited latitudes, that is from zero to 48°, by approximation.

<Text in the diagram:> Meridian line. – Centre of the gnomon. – Gnomon length. – *ʿAṣr* arc.

63 *On the construction of the universal sundial designed in terms of meridian altitude, for all inhabited latitudes, that is from zero to 48°, and for (timekeeping with) the sun, by approximation.*

If you want that, you have to find the meridian altitude. Determine the altitude *p. 157* of the hours for that meridian altitude, as already explained in Chapter 61. With this altitude as argument in the shadow table for each minute, take the corresponding entry: this will be the shadow of that hour. For the altitude

[1] I.e., the midpoint of the lower day-line, where the gnomon is fixed.

of the *ʿaṣr*, add to the midday shadow the length of the gnomon and this is its shadow. Enter the shadow of the *ʿaṣr* in the table as well and take the corresponding altitude: this is what is sought. Write it in a table. These hours are then fixed on a quadrant made out of wood or another material, or on a complete circle. If you want, trace a circle and divide it into 90 (parts); trace a radial line from that particular meridian altitude to the centre: this will be the day-line of that meridian altitude. Divide the radius by the shadow of the hours you want to construct: this will be the scale of the construction. The length has twelve (digits), and it is the quantity of the gnomon. Open (the compass) to the shadow of each hour and hold one leg of the compass fixed at the centre of the quadrant, and (place) the other one where it meets the day-line of that meridian altitude. When the hours are completed, do it also for the *ʿaṣr* in the same way. The construction is completed.

TABLE T.8. Shadow of the hours / shadow at the *ʿaṣr* / altitude at the *ʿaṣr*

h_m	1	2	3	4	5	6	*ʿaṣr*	h_m	h_a
10	183;53	137;08	97;45	78;56	70;26	68;03	80;03	10	8;31
20	140;32	69;23	48;44	38;47	34;25	30;58	44;58	20	14;56
30	95;17	46;25	32;06	24;57	21;43	20;57	32;47	30	20;06
40	73;43	37;31	23;49	17;53	15;06	14;19	26;18	40	24;30
50	61;32	28;53	18;53	12;54	10;53	10;03	22;04	50	28;33
60	54;09	24;58	15;44	10;33	7;51	6;56	18;56	60	33;17
70	49;39	22;32	13;45	8;33	5;30	4;10	16;22	70	36;13
80	48;59	22;07	12;38	7;20	3;52	1;54	14;07	80	40;49
90	46;25	21;47!	12;00	6;56	3;13	—	12;00	90	45;00

64 *On the construction of the conical sundial and the universal locust's leg, (valid) for all inhabited latitudes approximately.*

p. 147 To do this you should compile a table as we previously did and determine precisely the altitude of the hours. Take from a shadow table for each minute of argument the tangent of those altitudes and place (the results thus obtained) in tabular form (which will serve) at the requisite time.

Take a board of wood, flat in shape, or a circular cone (*mukḥul mudawwar*). Divide its whole (surface) into ten equal parts and trace (these divisions) as straight lines. Write on each of them the meridian altitude. Divide the day-line (corresponding to a) meridian altitude of 89° into the vertical shadow at the sixth hour. Consider this a scale, the gnomon length in terms of the parts of this scale being 12 parts. Open the compass to the vertical shadow of each hour and hold one leg of the compass firmly at the intersection of the horizon line with the day-line corresponding to that meridian altitude; where they intersect place the other leg on that day-line: this will be the point

(indicating) the hour. When you have completed (the marks for) all hours, join them (and you will get the hour-lines).

TABLE T.9. Table of the vertical shadow of the hours

h_m	1	2	3	4	5	6	ʿaṣr
10	0;21	1;03	1;28	1;48	2;03	2;07	2;01
20	1;01	2;05	2;58	3;43	4;11	4;22	3;12
30	1;30	3;06	4;29	5;16	6;37	6;56	4;23
40	1;57	3;50	6;03	8;04	9;31	10;04	5;29
50	2;21	4;59	7;38	11;09	13;15	14;19	6;32
60	2;39	5;46	9;09	13;38	18;21	20;47	7;53
70	2;54	6;23	10;28	17;50	26;06	32;58	08;47
80	2;57	6;30	11;24	19;39	37;19	68;03	10;00
90	3;06	6;56	12;00	20;47	44;47	—	12;00

{*Diagram*}

Shape of the locust's leg and of the *mukḥul*.

<Text in the diagram:> Horizon. – Place of the movable indicator *murī*. – Midday arc, universal for the inhabited latitudes. – (It is) universal within the seven (inhabited) climates, for (timekeeping with) the sun, by approximation.

65 *On the construction of the astrolabic quadrant for latitude 48°, which is the end of the inhabited countries.*

When we saw that the masters of this art (of instrumentation), (while) determining the time-arc from the altitude (are confronted with the following situation): When (the time-arc) is smaller than the altitude of the diameter, the thread will go outside the quadrant, in the direction of the nadir, on the quadrant constructed for latitude 30°,[1] and this is a mistake (made) by the ignorant people who have applied that which is mentioned. I thus chose to construct for them this quadrant in order to explain the incorrectness of what they have mentioned and applied about it from remote times up to the present days. This figure shows that the error is larger than 16°. *p. 84*

Explanation: When the altitude is 17° at the beginning of Cancer, its time-arc is 28;38°;[2] and its time-arc at Capricorn is 42;5°;[3] between them is a difference of 16;27°. The quadrant whose latitude is smaller than 48° is less corrupt than this. I want (to consider ?) the largest (error?) to be such that they would perhaps return to what they had firmly confirmed in their minds

[1] I.e., for Cairo.
[2] The accurate value is 28;32°.
[3] The accurate value is 45;04°.

concerning (the procedure for) latitude 30°, which is well-known. I have illustrated that its error is in the order of one or one and a half degree.

I you want to construct this quadrant, (know that) it is the northern (quadrant) mentioned at the beginning (of this book). So we do not need to repeat the manner of (its) construction (here). But we want to change the figure to (that of) another latitude, and it is necessary that a table be compiled for that latitude from the *Tables of Time-arc*, just as we compiled the table of the altitude circles for latitude 36°. And it is this:

TABLE T.10. Table for the construction of the altitude circles for latitude 48° north and south.

Cancer				Aries				Capricorn	
h	*t*	*h*	*t*	*h*	*t*	*h*	*t*	*h*	*t*
0	119;06	36	61;39	0	90;00	36	28;34	0	60;54
3	113;39	39	57;21	3	85;30	39	19;51	3	54;07
6	108;24	42	52;41	6	80;59	42	0;00	6	49;01
9	103;21	45	48;05	9	76;26			9	42;05
12	98;27	48	43;39	12	71;13			12	34;16
15	93;40	51	38;42	15	67;16			15	24;00
18	89;00	54	33;33	18	62;33			18	10;00
21	84;20	57	28;09	21	59;15				
24	79;48	60	22;11	24	52;31				
27	75;19	63	14;52	27	47;24				
30	70;49	65;35	0;00	30	41;41				
33	66;18			33	35;35				

Explanation of the construction of the altitude circles for latitude 48°, for which this table, which is on the back of this page, has been calculated. Trace a quarter circle bounded by two perpendicular radii. Then trace the circles of both tropics as you did previously. Take from the table the value corresponding to each altitude circle. Locate this value on the (altitude) scale of the quadrant and place the ruler upon it and at the centre. Make a mark at the intersection of the edge of the ruler with the day-circle you want. Once the marks of the tropics and of the equator are completed, join them as arcs of circle: these will be the appropriate altitude circles. If some quantity remains from the altitude circles, then hold one leg of the compass fixed at the centre and place the other one on the argument of each altitude circle on the side of the pivot (line). With this opening of the compass, add it to the side of the meridian line, and make the marks of the altitude circles. Join these marks and those of the smaller tropic by rotating the compass on the meridian line until the altitude circles are completed.

{*Diagram*}

Diagram of the astrolabic quadrant for latitude 48°.

66 *On the construction of an horary (quadrant) whose sixth (hour-line) has the (same) width as its first one, each of them having a uniform width.*

When I realised that (the hour-lines on) most of the horary (instruments) based on the meridian altitude or the midday shadow become closer and closer to each other so that the sixth and the fifth (hour-lines) are so close to each other that there is not even a slight distance between them and it is scarcely possible that (further) divisions be made between these two hour (curves), and they would not be (properly) distinguished (*wa-lā tuʿlam*), I invented this horary (quadrant), because it is superior to (other) horary (quadrants) of the same kind, (since) all of its (hour-lines) are uniformly spaced. *p. 133*

If you want (to construct it), trace a quarter circle bounded by two perpendicular radii. Divide the radius into 90 (parts). Place one leg of the compass at the beginning of the outer scale[1] and the other one at the centre. Trace an arc with this opening (of the compass) corresponding to the radius.[2] Move (the compass) so that you place (one leg) at the centre and the other one at the meridian altitude of Capricorn (expressed) in parts of the radius. Trace it as a circular arc: this will be the day-circle of Capricorn. Now place the compass on the meridian altitude of Aries, and trace an arc which will represent the equatorial day-circle. Likewise mark on all day-circles the quantity of the altitude of (each) hour. If you wish, (you can also) divide each day-circle into six <equal parts>:[3] mark the outer scale at each 10°, and these will be the marks of the hours (on the day-circle of Cancer);[4] <make also six marks on the day-circles of Aries and Capricorn.> When the marks of the hours are completed on these day-circles, join them as circular arcs, by successive approximations (of the compass). These will be the arcs of the hours. Write on them their number, and (write) the terrestrial latitude (on the quadrant).

{*Diagram*}[5]

Diagram of the hours for the specific latitude 30°.

<Text in the diagram:> There are two threads, one at the centre and the other one at the beginning of the outer scale.

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[1] Literally 'beginning of the quadrant arc', *passim*.

[2] On the illustration this arc is labelled the 'horizon', since it represents the hour zero.

[3] Only the portion of each day-circle below the 'horizon' should be divided into six equal parts. This alternative construction corresponds to an approximation of the exact curves.

[4] This is inexact: see the remarks in the commentary on p. 135.

[5] See Plate 6.

67 *On the construction of the seasonal hours (of an horary quadrant) for a specific altitude.*

p. 120 Trace a quadrant and divide it into 90 equal parts. Open (the compass) to the obliquity of the ecliptic and place one leg of the compass at the centre and trace with the other leg a circular arc: this will be the day-circle of Cancer.[1] Divide the region between the day-circle of Cancer[2] and the outer scale in two halves. Trace a circular arc (at this division): this will represent the equatorial day-circle. Place the ruler (on the outer scale) at the meridian altitude of the two tropics and of the equator. Mark each of these day-circles and join (these three marks) as a circular arc: this will represent the 'horizon'. Then place the ruler on the meridian altitude of each zodiacal sign among those (signs) and at the centre. Make a mark at the intersection of the ruler with the 'horizon'. Place the compass upon each of these marks and draw a circular arc: this will be the day-circle of (each) zodiacal sign you want. Next, place the ruler at the centre and upon the altitude of each hour. Make a mark at the intersection of the side of the ruler with the day-circle of that zodiacal sign. When the marks of the hours are completed for all day-circles, join them as arcs of circles, if possible, or draw them pointwise (as smooth curves). When the construction has finally been completed, write the name of the two (appropriate) zodiacal signs on each day-circle and the (corresponding) numbers on the hour arcs. Finally, take note that the outer scale also represents the day-circle of Capricorn.

{*Diagram*}

(Horary quadrant with) seasonal hours for latitude 36°.

<Text in the diagram:> This horary quadrant has a single thread.

68 *On the construction of the hours (of an horary quadrant) called 'hours of the chord'.*

p. 132 Trace a quarter circle bounded by two perpendicular radii. Divide the quadrant in 90 equal parts. Then divide one of the radii[1] into six equal parts and trace straight lines (from these divisions) to the beginning of the outer scale: these will be the day-lines. Write <the name of> (each) sign of the zodiac on its corresponding day-line. Place one leg of the compass at the beginning of the outer scale and the other one on the altitude of each hour at the beginning of this zodiacal sign, and transfer (this quantity) onto the day-line. Mark each day-line with six marks for the seasonal hours. When the marks of the hours are completed for each day-line, join those marks as arcs of circles if

[1] The text has erroneously 'Capricorn'.
[2] The text has 'Capricorn'.
[1] Namely, the vertical one.

possible, and if not, as linear segments, with the compass (!),[2] as you would trace the hour (lines) of a horizontal sundial. And if it is not possible to join (the marks) either as circular arcs or as linear segments, then join them pointwise (as smooth curves). Write on the (hour-lines) their number and (write also on the horary quadrant) the terrestrial latitude for which you have drawn (it).

{*Diagram*}

Diagram of the hours of the chord for latitude 36°.

< Text in the diagram: > This quadrant has two threads. – Position of the second thread.

69 *On the construction of the seasonal hours (of an horary quadrant), called 'hours of the harp' (*junk*).*

Trace a quarter circle bounded by two perpendicular radii. Divide the quadrant in 90 equal parts. Trace an imaginary line from the meridian altitude of Capricorn to the vertical radius, perpendicular to the horizontal radius. Mark the intersection of this line with the vertical radius. Take (one half of the segment) underneath this mark towards the centre and trace an imaginary line (from there to the beginning of the outer scale): this will be the day-line of Capricorn. Divide (the portion) between (the end of) the line of Capricorn and the end of the outer scale in two halves, and trace again an imaginary line (from there) to the beginning of the outer scale: this will be the day-line of Aries. Trace a straight line from the beginning of the outer scale to its end: this will be the day-line of Cancer. Place the ruler at the centre and at their meridian altitude and make a mark on each of these day-lines. Join these three marks to form the arc of the sixth (hour). Place the ruler at the altitude of the first (hour) and at the centre and make a mark on the three day-lines, and likewise for the second, third, fourth and fifth (hours). When the marks of the hours are completed, join them (by means of smooth curves). Place the ruler at the centre and at the meridian altitude of the remaining zodiacal signs, and mark their intersections with (the arc of) the sixth hour. Trace straight lines from these points to the beginning of the outer scale: these will be the day-lines of (those remaining) zodiacal signs. Write their names and the number of the hours. *p. 129*

{*Diagram*}

Diagram of the hours of the harp.

< Text in the diagram: > This quadrant has a single thread.

[2] It makes no sense to draw linear segments with a compass; here the text must be corrupt.

70 *On the construction of the hours (of an horary quadrant), called 'hours with the branches'.*

p. 124 Trace a quarter circle bounded by two perpendicular radii. Divide the outer scale into 90 equal parts. Trace the straight day-lines of the zodiacal signs, each of them (beginning) at their (respective) meridian altitudes, as lines parallel to the meridian line. Write on each day-line (the names of) its two (corresponding) zodiacal signs. Place the ruler at the centre of the quadrant and at the altitude of the first hour for each of the day-lines and make a mark on each of them. Then place the ruler at the centre and at the altitude of the second (hour) and make the marks in the same way on each of (the day-lines). Then place the ruler at the centre and at the altitude of the third (hour) for each day-line and do again the marks. Do the same (operation) for the fourth and fifth (hours). When the marks of the five hours are completed, join them: these will be the hour arcs. The (inside of the) outer scale will represent the sixth (hour).

{*Diagram*}[1]

Diagram of the hours with the branches.

<Text in the diagram:> This quadrant has a single thread.

71 *On the construction of the hours (of an horary quadrant), called 'hours with the nonagesimal (scale)'.*

p. 136 Trace a quarter circle bounded by two perpendicular radii, and divide (the outer scale) into 90 equal parts. Divide the eastern line likewise (into 90 equal parts). Then place one leg of the compass at the centre of the quadrant and at the complement of the meridian altitude of the corresponding zodiacal sign (on the radial scale), and transfer this (quantity) to the meridian line, until you you have done it for all zodiacal signs. Move the compass so that you can lay one leg at the end of the quadrant, and the other one at each mark of the zodiacal signs. Then trace an arc, which will be the day-circle of that zodiacal sign. Place one leg of the compass again at the centre, and the other one at the complement of the altitude of the hour (on the radial scale), expressed in parts of the radius. Make a mark with this other leg on the day-circle of that zodiacal sign you want. Mark this way the altitude of each hour for each of the zodiacal signs, and do it until you reach the fifth hour. Once you have placed the whole marks of the signs, join them as arcs of circles by successive approximations (with the compass). Write (the names of) the two (corresponding) zodiacal signs on each day-circle as well as the numbers of the hours.

[1] See Plate 7.

{*Diagram*}

Diagram of the hours for latitude 36°.

< Text in the diagram: > This quadrant has a single thread.

72 *On the construction of the hours (of an horary quadrant), called 'hours with the bowed scale' (*sāʿāt al-shaẓiyya*).*[1]

Trace a quarter circle bounded by two perpendicular radii. Divide the outer scale into 90 equal parts, and divide one of the radii into 90 equal parts. Place the ruler at the centre and at each fifteen degrees of the outer scale, and trace straight lines, which will be the day-lines. Write the names of the (respective) zodiacal signs on them. Place one leg of the compass at the centre and the other one at the altitude of the first hour (measured on the radius scale), and transfer this (quantity) with this opening to the day-line of that zodiacal sign, and make a mark (there). Place the compass at the altitude of the second (hour) and transfer (this quantity) to the day-line of that sign, and make a second mark. Do this operation for all hours. When the marks of the hours are completed, join them with the compass (as circular arcs) if possible, and if not, join them pointwise (as smooth curves). These will be the arcs of the seasonal hours. Write their numbers on them and the terrestrial latitude. *p. 132*

{*Diagram*}

Diagram of the hours for latitude 36°.

< Text in the diagram: > This quadrant has a single thread.

73 *On the construction of the hours with the circles of equation.*

Trace a quarter circle bounded by two perpendicular radii, and divide the outer scale into 90 equal parts. Place one leg of the compass at the beginning of the outer scale and the other one at 45° on the arc (of the quadrant). Transfer this (quantity) to the eastern line and make a mark. Then move the compass so *p. 122*

[1] The reading of this word is not certain (both manuscripts have شطية or perhaps شطبة). The usual meaning of *shaẓiyya* is 'splinter, sliver'; in the context of technology and instruments, however, it designates a narrow movable component used as a radial cursor or scale, or a star-pointer. Another meaning given by Kazimirsky (*Dictionnaire Arabe-Français*, s.v.) is that of arc, bow: this, in my opinion, would aptly fit the narrow, curved longitude scale found on this instrument. Viladrich (2000, p. 313) reads *al-shaṭaba*, acknowledging not to know the meaning of the word, but nevertheless translating it as 'sliver', as though it were *shaẓiyya*. Now *shaṭba* (collective) refers to the branches of a palm-tree, which could indeed make sense if it is intended to designate the hour curves as resembling the twigs of a palm (see Fig. 3.11 on p. 131). Or perhaps should we read *shiṭba* or *shuṭba*, "Trait ondulé d'une lame damasquinée" (Kazimirsky)? Could this refer to the curved longitude scale which runs alongside the sixth hour-line? I have decided to adopt what I consider the most plausible of these possibilities, reading *shaẓiyya* in the sense of an bowed scale. *Allāhu aʿlam.*

that you place its legs at the centre and upon this mark. Trace a small quarter circle, which will be the day-circle of Capricorn. On that line, divide (the space) between the day-circle of Capricorn and the outer scale in two halves, < and make a mark. Place the leg of the compass upon this mark and trace a median arc. > This (median arc) will be the arc of Aries. Place the ruler at the centre and upon the altitude of the sixth (hour) for Aries, for Capricorn and for Cancer, and make marks on the intersections of the ruler with their day-circles. You should know, however, that the day-circle of Cancer is the outer scale itself. Join these three marks, and you will get the arc of midday. Place the ruler at the centre and at the meridian altitude of Taurus, Gemini, Scorpio and Sagittarius, and mark the intersections of the ruler with the arc of the sixth (hour). Then place one leg of the compass at the centre and the other one upon each of these marks, and trace circular arcs, which will be the required day-circles. Write the names of the (respective) pairs of zodiacal signs on each of them. Place the ruler at the altitude of each hour and at the centre (for each zodiacal sign), and mark the position of its intersection with the day-circle of the sign. Once the marks of the hours are completed, join them as circular arcs with the compass: these will be the arcs of the seasonal hours. Write their numbers (along them).

{*Diagram*}

Diagram of the hours for latitude 36°.

< Text in the diagram: > This quadrant has a single thread.

74 *On the construction of the universal horary quadrant, which works approximately for all inhabited latitudes, that is from zero to 48°.*

p. 214 This is the best and most excellent of horary instruments. For that reason we end with it our discussion of ten quadrants. These quadrants are specific for a particular latitude: their designs are limitless and their explanation would get very lengthy; (but) the abridgment achieved the same purpose (*wa-l-ikhtiṣār balaghahu*).

If you want to construct it, trace a quarter circle and divide it into 90 (equal parts) after you have bound it by two perpendicular radii. Place the ruler at each 15° of those divisions and at the centre, and trace straight lines, which will be the hour-lines. Divide the radius in two halves and hold one leg of the compass fixed (at its midpoint) and trace a semicircle with the other one, which will be the meridian altitude arc. Divide the meridian line into 60[1] equal parts and take the sine of each five (degrees), or otherwise, and trace straight lines parallel to the eastern line: these will be the lines of the basic sines. On the hour-lines, write their numbers, and on the arc (write) 'meridian

[1] The text has 90.

altitude arc'. With this quadrant you can determine the time-arc for each solar altitude better than with the universal horary quadrant, for (the hours) are more widely spaced than the hours (of the latter).

A straight line may be traced from the beginning of the outer scale to its end. Write '*ʿaṣr*' on it. This (line) is straight; (another version) can also be drawn pointwise (as a smooth curve) because of its curvature, and in this case we have left it out because it is well-known, whereas the (other) one is much less usual.[2]

{*Diagram*}

Diagram of the hours (of the horary quadrant valid) for all inhabited latitudes, for (timekeeping with) the sun, and for (timekeeping with) all stars whose declination are smaller than the obliquity of the ecliptic, by a good approximation.

<Text in the diagram:> This quadrant has a single thread.

75 *On the construction of the hours with the square angle (*al-zāwiya*).*[1]

Trace an imaginary quarter circle bounded by two perpendicular radii. Divide that quarter circle into 90 equal parts, also imaginary. Trace the line of the chord of the quadrant: this will be the longest side of the square angle.[2] Place the ruler at the centre and on each of the imaginary divisions (of the quarter circle), and mark the intersections of the side of the ruler with the chord. Once you have completed the marks of the chord, you get something with which you can measure the altitude, provided it is done according to the illustration. *p. 126*

Next divide (each) radius, which is one of the two equal sides of the square angle, into three (equal) parts in both directions (and mark these divisions on both radii). Trace a straight line (joining the two marks closer to the centre): this will be the day-line of Capricorn. Divide (the space) between the day-line of Capricorn and the diagonal, which is the day-line of Cancer, into six (equal) parts in both directions, and trace straight lines (between) those (divisions): these will be the (remaining) day-lines. Place the ruler at the centre and on the altitude of each hour, and mark the intersections of the side of the ruler with the corresponding day-line, so that you complete the hour (marks), and then join them (to form the hour curves).

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[2] Actually the illustration displays a curve for the *ʿaṣr*, virtually drawn as a semicircle, which must be identical to the second *ʿaṣr* curve described in Ch. 77.

[1] The instrument derives its name from the form of the right angled isosceles triangle on which the horary markings are traced. The term *zāwiya* refers in this context to the geometrical instrument with this shape, curiously called a *square* in English (but cf. German Winkel).

[2] I.e., the hypothenuse of the sight angled isosceles triangle.

{*Diagram*}[3]

Diagram of the 'hours with the angle' for latitude 36°.

< Text in the diagram: > (This is) with a single thread at the centre.

76 *On the construction of hour markings on the flat 'locust's leg' or on the circular conical dial, its gnomon being fixed.*

p. 140 Take a flat board of wood or something similar, or a circular cone. < ... > Divide them into 90 equal parts and write on each division[1] its (corresponding) meridian altitude. Trace curved (!) lines[2] converging to a single point. Then trace a quarter circle and divide it into 90 parts.[3] Place the ruler at the centre and at the altitude of the hour, and make a mark at the intersection of the side of the ruler with the corresponding day-line, so that you complete all of the hour (marks) for all zodiacal signs; (do) likewise the arc of the *ʿaṣr*. Join these (marks to form the hour curves) and write their numbers on them. You should know that the gnomon length is (the space) between the sixth (hour) and the (day-) line of (meridian altitude) 90° at right angles.[4] And you should also know that (the lower extremity of) the line of (meridian altitude) 90° is the point directly below the gnomon (*masqaṭ ḥajar al-shakhs*).[5]

{*Diagram*}

The altitude of the sun can be determined with this quadrant.

< Text in the diagram: > Arc of the beginning of the *ʿaṣr*. – Midday-circle. – Centre of the fixed gnomon. – Length of the fixed gnomon.

On the determination of this table. Take the sine of the meridian altitude from the tables compiled for each minute of argument (*al-jadāwil al-maḥlūla daqīqa daqīqa*). Take one fourth of the sine of the meridian altitude and find its arc: this will be the altitude of the first (hour). Take half the sine of the meridian altitude and find its arc: this will be the altitude of the second (hour). Take one half plus one fifth of the sine of the meridian altitude and find its arc: this will be the altitude of the third (hour). Take two thirds plus one fifth of

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[3] See Plate 8.

[1] The text has 'day-line'.

[2] These lines should in fact be straight.

[3] That quarter circle should to be centred in the upper corner opposite the convergence point of the day-lines, with a radius small enough so that its outer scale will not overlap the day-lines.

[4] This sentence is unclear, but the illustration suggests to interpret it as the width of the horizontal scale. In fact, the gnomon length does not make any difference on this instrument, since only the direction of the shadow allows to tell the time.

[5] *Masqaṭ al-ḥajar*, literally the "falling of the stone", is a standard expression which denotes the orthogonal projection of a point onto a horizontal surface below that point. See al-Bīrūnī, *Tafhīm*, p. 6, § 21.

the sine of the meridian altitude and find its arc: this will be the altitude of the fourth (hour). Take two thirds plus one fifth plus one tenth of the sine of the meridian altitude and find its arc: this will be the altitude of the fifth (hour). This procedure is approximate, for (timekeeping with) the sun, for the inhabited latitudes.

I carried out (the operations) by versed sines and sines, and I have found it to be a very good approximation. I have thus chosen to make for its (purpose) a table, because of the great difficulties in calculating the altitudes of the hours for all latitudes, since inevitably when you change the latitude you have to compile a (new) table for it. The commentary would become too long. (The procedure) would remain specific to the latitude for which you have made the calculation, and it would not be possible to label it 'universal'. So, when I saw that this table is a very good approximation and that its usefulness is of a great generality, then I consigned it in this book of mine so that it be useful and that it renders easier the tasks of whoever wants to construct conical sundials and 'locust's legs', or other horary (instruments) specifically for (timekeeping) with the sun, and for all inhabited latitudes. When it is labeled 'universal', it means that it is (intended) for all inhabited latitudes, by an approximation that is very good. If it is thought to be universal for (timekeeping with) the sun and the stars, for all inhabited latitudes and (even) for the desolate (uninhabited) countries (*al-khirāb*), then this is a big mistake.

TABLE T.11. Table of the altitude of the hours, for (timekeeping with) the sun and with the stars whose declinations are smaller than the obliquity of the ecliptic

h_m	h_1	h_2	h_3	h_4	h_5	h_a	h_b
10	2;31	5;0	7;0	8;39	9;40	8;31	7;26
20	4;53	9;49	13;49	17;12	19;14	14;56	11;54
30	7;11	14;30	20;30	25;41	28;54	20;6	15;0
40	9;15	17;45	27;45	33;52	38;25	24;32	17;24
50	11;2	22;32	32;25	42;55	47;48	28;33	19;25
60	12;[30]	25;40	37;20	48;39	56;51	33;17	21;11
70	13;35	28;2	41;8	54;32	65;17	36;13	22;55
80	13;45	28;29	43;34	58;36	72;10	40;49	24;52
90	14;30!	30;0	45;0	60;0	75;0	45;0	26;34

This table is valid for all inhabited latitudes by approximation, that is from latitude zero to 48°.

<Remark:> As for the altitude of the beginning of the *ʿaṣr* and of its end, it is exact, not approximate.[6]

[6] In **P** there follows a note in a later hand which seems to conclude the extant portion of the treatise in this manuscript: "Our purpose is achieved. May the person who finds (it to be)

77 *On the construction of the arcs of the* ʿaṣr *on the sine quadrants.*

p. 176 The arc of the *ʿaṣr* on all (these instruments) is universal, and its greatest variation in shape is (when it is drawn) on the sine quadrants. For that reason we have chosen to construct and to explain each arc that differs from the other ones. There may be more than five (different) forms, but the abridgment (to five) is here sufficient.

If you want to construct the first (kind of) marking (*qaws*) which is well-known and called the duodecimal shadow lines, < make a mark on the twelfth division of the sexagesimal scale on the vertical radius, counting from the centre, and trace a straight line from that mark to the outer scale, parallel to the horizontal radius. >

The second one is the one some people make as a straight line, but this is faulty: the correct procedure leads to a pointwise curve (*nuqaṭan muʿwajjatan*) based on the sine. *Explanation (thereof)*: You have to place the ruler on the meridian altitude and at the centre. Enter with the altitude of the *ʿaṣr* along the sine until (it meets) the side of the ruler; make a mark (there). Continue this operation until the meridian altitudes (in the table) have been exhausted. Then (join these marks by) drawing a pointwise curve.

The third one: Place one leg of the compass at the centre and the other one on the meridian line at the sine of the altitude of the *ʿaṣr*, and move the leg that is on the sine of the altitude of the *ʿaṣr* until you can lay it upon the radial line of the meridian altitude. Make a mark on the quadrant (at this position). When the marks of the *ʿaṣr* have been completed, join them (to form) an arc.

The fourth one: Place one leg of the compass at the centre and the other one upon the sine of the meridian altitude, and move the leg that is on the sine of the meridian altitude until you can lay it upon the radial line corresponding to the altitude of the *ʿaṣr*. < Make a mark there, and when the marks are completed, > join them pointwise (as a smooth curve). This < ... >

< *The fifth one*: Place one leg of the compass at the centre and the other one on the sine of the meridian altitude, and move the leg that is on the sine of the meridian altitude until you can lay it upon the line of the sine of the altitude of the *ʿaṣr*. Make a mark there, and continue this operation until the marks are completed. Then join them pointwise (as a smooth curve). >

< ... > and the one that is before it has the appearance of a *jūkān*.[1]

You should know that on the sine quadrant there is no need for any of these five arcs (of the *ʿaṣr*), but we only wanted to instruct whoever wants to construct these markings.

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defective correct it. The tome is finished. Praise belongs to God, the Unique, the Grantor of success! *God is sufficient for me! And how sublime a Guardian is He!* (*Qurʾān*, III, 167)".

[1] From Persian *čawgān*: a stick with curved extremity, also designating the game of polo with which it was played. See Quatremère's 10-page footnote on this word in *Mamlouks*, I.1, pp. 121–132 and the article "čawgān" in EI^{2} (by H. Masse); see also *Alf layla wa-layla*, 11:46–48, 12:9–17.

{*Diagram*}[2]

Diagram of the universal *ʿaṣr* curves[3] on the sine quadrant.

78 *On the construction of the linear astrolabe.*

Take a flat ruler or a stick with octagonal, hexagonal, square or triangular *p. 62* cross-section. If it is flat, write the scales of construction (*jadāwil al-ʿamal*) on it. Divide it from the lower handle (*miqbaḍ*) to the upper handle (*mumsik*) in 90 unequal parts, following the divisions of the sine, as you already divided one of the arms of the (instrument) with two branches. For that reason we have not described the construction of this astrolabe together with all the (other) astrolabes. In fact it does not have their shape at all, nor is it of a similar kind. It rather has the shape of a ruler, or of (the instrument) with two branches. So we have mentioned it at an appropriate place.

If you want to construct it, then hollow out two holes at both sides, one at the upper handle, the other at the edge (? *uskuffa*) of the lower handle. Divide (the space) between the two holes in 90 unequal parts, following the divisions of the sines (as if they were projected) from (an altitude) scale. Next divide the length of the stick at another place into 60 equal parts, and mark the sine of the arc at each 5°, or as you like. Take from these parts the difference of the sine from the arc. Move the compass with this opening onto one of the sides of the stick, from the lower to the upper handle. Write on them the altitude arguments. Take a thread whose length corresponds approximately to twice plus one fourth and one sixth the distance between the lower and upper handles.[1] As for the exact (procedure), divide (the space) between the the upper and lower handles into sixty equal parts and take 144;50 of these parts: this will be the length of the thread, without (counting the length needed for) the two knots of the thread.

As for the scales marked on it, it is not necessary for us to mention them, since they are taken from the tables already mentioned.[2] It is not possible to illustrate it on this page, apart from that figure (below). There is nothing on (the linear astrolabe) better than measuring the altitude, and for this reason we have reproduced it (here).[3]

{*Diagram*}

Diagram of the linear astrolabe, an instrument which is no longer found nowadays.

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[2] See Plate 15.

[3] The text has ‘lines’.

[1] We note that $(2+\frac{1}{4}+\frac{1}{6})60 = 145$, which is an approximation for 144;50.

[2] Najm al-Dīn has never presented any of the tables that would be required for constructing a linear astrolabe.

[3] The diagram indeed seems to illustrate an altitude measurement with the linear astrolabe, but the geometric configuration of the threads is incorrect.

<Text in the diagram:> Rest of the thread (as seen) from the face of the astrolabe. – Face of the linear (astrolabe). – Divisions of the altitude circles for measuring the altitude. – Thread of the plumb-line when the altitude is 59°. – Rest of the thread (as seen) from the back of the astrolabe. – Know of the plumb-line. – Plumb-line. – Lower handle.

79 *On the construction of the horizontal sundial (with) the day-circles.*[1]

p. 188 Divide the sundial plate into four quadrants and trace a line at the middle, which will be the meridian line. Trace a circle whose centre is <on> the meridian line and trace a line going through the centre <and> intersecting the meridian line (at right angles): this will be the east-west line. From the point of intersection of the east-west line with the circle,[2] measure <on the circumference> the azimuth of each hour in the direction of these azimuths, and mark it. Place the ruler upon that mark and <at> the centre, and open the compass to the horizontal shadow of the hour. Place one leg at the centre and the other one where it cuts the side of the ruler: this is the location of (the mark for) the hour. Do this for both solstices. Then join (the marks of) the hours for both parallels (of the solstices). As for the day-circle of Aries, trace it as a straight line (perpendicular) to the midday shadow. (Trace the curves for) the remaining zodiacal signs by means of the horizontal shadow of the hours. Understand this and you will get it right.

{*Diagram*}

<Horizontal sundial with> seasonal hours for latitude 36°.

<Text in the diagram:> North, South, East, West. – First, second, ..., eleventh (hour). – (Zodiacal signs).

80 *On the construction of the horizontal sundial bearing the altitude circles and the seasonal hours.*[1]

p. 189 The (construction of the) hours is as we have previously explained. For the altitude circles, open the compass to the (horizontal) shadow of the argument of the altitude circle you want, in terms of the parts of the gnomon length. Place one leg of the compass at the centre of the horizontal sundial and the other one upon the declination curve of Capricorn. Trace a circular arc until you can connect (it with the same declination curve on the other side). If (this

[1] The copyist of **D** has copied the text of Chapter 79 on f. 47r but has accompanied it by the illustration of Chapter 80. On the verso of the same folio he has then copied the text of Chapter 80, which he imagined to be the wrong text so that he stroke it out. On f. 47r he then began a new Chapter 80 with the same text (without variant) as that of Chapter 79, and which is accompanied by the illustration belonging to Chapter 80!

[2] The text has ‘meridian line’.

[1] This is the text that is crossed out on f. 47v. Its illustration has mistakenly been placed on f. 47r.

circular arc rather) ends on the declination curves (of both solstices), trace two circular arcs from the declination curve of Cancer (to that of Capricorn), (one) on the eastern side and (the other one) on the western side. The altitude circles are thus completed. Number them, and number the hours as well.

{*Diagram*}

Horizontal sundial for latitude 36°.[2]

<Text in the diagram:> North, South, East, West.

TABLE T.12. Table (for constructing) the horizontal sundial for latitude 36°, with the seasonal and equal hours, their altitudes and azimuths, their shadow lengths, at the beginning of Cancer specifically, and with the altitude, the shadow and the azimuth, (all of them expressed in terms of) the time-arc (tabulated) for each 3°

T	*h*	*u*	*v*	*az*	*T*	*h*	*u*	*v*	*az*
3	2;12	312;23	0;27	28;00 N	57	44;1[3]	1[2];20	11;41	0;46 S
6	4;24	155;49	0;54	26;24 N	60	46;39	11;19	12;42	2;29 S
9	6;36	103;45	1;23	24;49 N	63	49;06	10;23	13;52	4;38 S
12	8;48	77;35	1;51	23;14 N	66	51;33	9;3[2]	15;05	6;14 S
15	11;01	61;38	2;21	21;39 N	69	53;[5]9	8;43	16;30	9;17 S
18	13;13	51;07	2;49	20;04 N	72	56;24	7;59	18;03	11;46 S
21	15;34	43;05	3;20	18;29 N	75	58;44	7;18	19;44	14;18 S
24	17;55	37;07	3;53	17;54 N	78	61;00	6;39	21;39	17;18 S
27	20;16	32;26	4;26	15;20 N	81	63;15	6;03	23;49	20;34 S
30	22;37	28;43	5;00	13;40 N	84	65;30	5;29	26;21	24;05 S
33	24;58	25;47	5;36	12;00 N	87	67;45	4;55	29;18	28;16 S
36	27;20	23;14	6;16	10;22 N	90	70;00	4;22	32;58	32;18 S
39	29;46	20;57	6;52	8;46 N	93	72;00	3;54	36;56	36;21 S
42	32;11	19;02	7;33	6;02 N	96	73;40	3;31	40;55	40;25 S
45	34;36	17;22	8;17	5;40 N	99	75;00	3;13	44;47	45;35 S
48	37;00	15;55	9;03	4;06 N	102	76;15	2;57	48;59	58;00 S
51	39;24	14;37	9;51	2;31 N	105	77;11	2;43	52;43	73;00 S
54	41;48	13;26	10;45	0;54 N	108;21	77;35	2;38	54;32	90;00 S

[2] On this illustration the north, contrary to Najm al-Dīn’s usage, is below the gnomon.

Continuation of the table (for constructing) the horizontal sundial for latitude 36° with the seasonal and equal hours, their altitudes and azimuths, at the beginning of Capricorn

T	*h*	*v*	*u*	*az*
3	2;02	338;[30]	0;25	31;39 S
6	4;04	168;50	0;50	33;24 S
9	6;06	112;22	1;17	35;38 S
12	8;08	83;58	1;41	37;09 S
15	10;02	67;49	2;07	39;01 S
18	11;52	57;08	2;31	41;00 S
21	13;3[8]	4[9];27	2;55	43;06 S
24	15;20	43;47	3;17	45;15 S
27	17;00	39;14	3;40	47;30 S
30	18;40	35;33	4;03	49;33 S
33	20;15	32;28	4;25	52;38 S
36	21;36	30;17	4;46	54;43 S
39	22;50	28;27	5;04	57;20 S
42	23;56	27;02	5;20	69;06 S
45	25;00	25;44	5;36	62;48 S
48	26;00	24;35	5;51	65;41 S
51	26;56	23;38	6;06	68;41 S
54	27;48	22;46	6;20	71;40 S
57	28;38	21;59	6;33	74;44 S
60	29;26	21;15	6;46	77;46 S
63	29;56	20;49	6;55	80;48 S
66	30;15	20;3[2]	7;01	83;52 S
69	30;21	20;28	7;02	86;56 S
71;39	30;25	20;25	7;03	90;00 S

TABLE T.13. Table of the horizontal and vertical shadows of the hours, the shadows of the beginning of the *ʿaṣr*, and their azimuths, at the beginning of the zodiacal signs

hours	Cancer		Gemini Leo		Taurus Virgo		Aries Libra		Pisces Scorpio		Aquarius Sagittarius		Capricorn	
	u	*v*	*u*	*v*	*u*	*v*	*u*	*v*	*u*	*v*	*u*	*v*	*u*	*v*
1	50;55	2;50	51;27	2;48	51;51	2;46	56;08	2;34	66;16	2;24!	81;28	1;44	84;18	1;[4]1
2	23;10	6;13	23;20	6;11	24;34	[5];51	27;09	5;19	32;38	4;27	41;24	3;28	43;[5]9	3;16
3	13;2[2]	10;48	13;28	10;43	15;01	9;[3]4	17;10	8;22	21;43	6;37	27;05	5;20	30;28	4;45
4	[7];39!	18;08	8;21	17;14	9;13	10;34	12;14	[11];47	16;25	8;45	21;49	6;36	24;42	5;49
5	4;19	33;15	27;14!!	28;25	6;47	21;13	9;[3]5	15;01	14;05	10;13	19;[1]5	7;30	21;[1]9	6;44
6	2;38	54;32	3;22	[4]2;35	5;28	26;23	8;43	1[6];31	13;07	10;[5]8	17;58	8;01	20;25	7;03
beg. of *ʿaṣr*	14;38	9;50	15;22	9;22	17;28	8;15	20;43	6;57	25;07	5;44	29;58	4;49	32;25	4;26
end of *ʿaṣr*	26;38	5;25	27;22	5;16	29;28	4;39!	32;43	4;23	37;07	3;[5]3	41;58	3;25	44;25	3;14
	az of *ʿaṣr* 2;0						*az* of *ʿaṣr* 24;44						*az* of *ʿaṣr* 52;46	

TABLE T.14. Table of the altitude at the hours and their 'times' (i.e. time-arc), of the altitude at the *ʿaṣr* and its end, and of the rising amplitude at the beginning of the zodiacal signs

hours	Cancer		Gemini Leo		Taurus Virgo		Aries Libra		Pisces Scorpio		Aquarius Sagittarius		Capricorn	
	T	*h*	*T*	*h*	*T*	*h*	*T*	*h*	*T*	*h*	*T*	*h*	*T*	*h*
1	18;03	13;16	17;36	13;08	16;24	13;02	15	12;04	13;36	10;16	12;24	8;23	11;17	8;06
2	36;07	27;24	35;12	27;14	32;47	26;00	30	23;51	27;13	20;11	24;48	16;09	23;13	15;16
3	54;10	41;55	52;48	41;43	49;11	38;35	45	34;54	40;49	28;54	37;12	23;54	35;50	21;30
4	72;14	56;30	70;24	[5]5;11	65;34	50;30	60	44;28	54;26	36;06	49;36	28;48	47;46	25;[5]8
5	90;17	70;11	88;00	67;08	81;58	60;31	75	51;24	68;02	40;27	62;00	32;00	59;4[3]	29;06
6	108;21	77;35	105;37	74;16	98;21	65;32	90	54;00	81;39	42;28	74;23	33;44	71;39	30;25
beg. of *ʿaṣr*	51;55	39;21	47;24	37;53	42;54	34;30	38;16	30;04	34;56	25;32	33;47	21;49	32;51	20;16
end of *ʿaṣr*	32;11	24;17	30;14	23;41	27;38	22;10	25;09	20;07	24;20	17;55	23;[3]1	15;57	23;37	15;07
	ψ 29;38		ψ 25;21		ψ 14;18		ψ 0;0		ψ 14;18		ψ 25;21		ψ 29;38	

81 *On the construction of the horizontal sundial with the hour-angles.*

Trace an imaginary circle and divide it into four quadrants, each quadrant *p. 189* being divided into 90 equal parts. Place the ruler (on the outer scale) on the value of the azimuth of the hour-angle and at the centre. Open the compass to the shadow of the altitude. Place one leg of the compass at the centre and the other one where it cuts the side of the ruler. Leave a mark there. Continue to do this until you have completed the marks of the hour-angles for Capricorn. Then do the same operation for Cancer. Once the marks of Cancer and Capricorn are completed, join them as straight lines: these will be the lines of the hour-angle. Number them. If the marks of Capricorn are completed,[1] join (the marks of Cancer with) the marks of the equator,[2] and if the marks of the equator are completed, join (the marks of Cancer with) those of Taurus, and if these have (also) been completed, join (the marks of Cancer with) those of Gemini. The construction is then complete.

{*Diagram*}

Horizontal sundial with the hour-angle for latitude 36°.

<Text in the diagram:> Centre. – Gnomon length.

82 *On the construction of the horizontal sundial with the equal hours.*

This is just like you did previously for the seasonal (hours), except that some- *p. 189* times you have to join (the marks of) the hours starting from sunrise, sometimes starting from midday. Join the two (marks for each hour line) between the day curves of Capricorn and Cancer. If the day curve of Capricorn is completed, then use the day curve of Aries. And if (the latter is likewise) completed, use the day curve of Gemini. Then the hours are completed, provided you number them.

{*Diagram*}

Horizontal sundial with equal hours for latitude 36°.

<Text in the diagram:> Gnomon length. – East, West. – Cancer (*bis*), Aries/Libra, Capricorn (*bis*).

83 *On the construction of the shadow circle, with which one can determine the altitude and the azimuth (of the sun) at any time.*

If you want to construct it, then draw a circle and divide it in four quadrants, *p. 168*

[1] I.e., if all marks have been made on this declination curve (because the hour-angle is not defined for this declination or because it would be outside the range of the sundial plate).

[2] I.e., for each hour-angle with this situation, use the marks of Cancer and of the equator to trace the line of the hour-angle.

each being divided into 90 (equal) parts. Trace the azimuth lines from (the divisions of the circumference) to the centre of the circle. Divide (the radius) from the centre to the circumference according to the shadow of each altitude you want, and these divisions will give you a scale. On this scale, take the shadow of each altitude. Place one leg of the compass at the centre, and with the other one (placed successively at each of those divisions), trace a complete circle, or if you want, a section of a circle (extending) from the rising amplitude of Cancer to its setting amplitude: these will be the altitude circles. Take twelve parts on the scale: this will give you the gnomon length. If you want you may (furthermore) trace the shadow circles: these are equidistant (concentric) circles, whereas the altitude circles are not equidistant. We have thus done all the markings (of this instrument) on a single plate of marble. Write on it all that can be determined with it. We shall later mention that at the appropriate place (in this book) and illustrate it, God Almighty willing.

{*Diagram*}

< Diagram of the shadow circle. >

< Text in the diagram: > Gnomon length. – Rising amplitude of Capricorn. – Setting amplitude of Capricorn. – It is made on a flat surface, and (it works) for all latitudes. – (The markings for) the rising and setting amplitudes of Capricorn are in addition to the azimuth lines (drawn at each 10°).

84 *On the construction of the (instrument displaying) the time-arc as a function of the azimuth (*al-dāʾir al-murakkab ʿalā ʾl-samt*).*

p. 167 Draw a circle and divide it into four quadrants, each divided into 90 (equal parts). Trace imaginary lines from the rising amplitude of the beginning of each zodiacal sign to the centre, and divide the radius into seven parts, equal or not, as you wish. Place the ruler upon the (graduation of the) azimuth that corresponds to a specific time-arc, and make a mark on the day-circle of that degree of the ecliptic. When the marks are completed, join them as circular arcs, and write on them the values of the time-arc and of the equal and seasonal hours, in case the construction has the seasonal hours.

It is (still) better to (proceed as follows): make the marks where the time-arc corresponds to the azimuth at each zodiacal sign and join the marks as circular arcs or pointwise (as smooth curves). Then place one leg of the compass at the centre and (the other one) on the mark of each zodiacal sign and trace an arc of circle from the rising amplitude to the setting amplitude. Write the values of the time-arc (on the curves of the time-arc) and the names of zodiacal signs (on the day-circles). It is still better to fit it with the day-circles that are drawn on the *musātira*. This sundial is held fixed on the ground, and its gnomon has no specific length. You could also install on (the gnomon) a (vertical) quadrant of brass designed to measure the altitude (of the sun).

The curves of the time-arc are (displayed) as functions of the azimuth. The construction is completed, God Almighty willing.

{*Diagram*}

<Diagram of (the instrument displaying) the time-arc as a function of the azimuth.>

<Text in the diagram:> (Zodiacal signs). – This horizontal sundial (*rukhāma*) was made by Nūr al-Dīn al-Iskandarī[1] in the courtyard of the Old Mosque in Fusṭāṭ (*fī saṭḥ al-Jāmiʿ al-ʿAtīq bi-Miṣr*).[2] There was a quadrant of brass on it, with which he – may God have mercy upon him – used to measure the altitude (of the sun).

85 *On the construction of (the sundial displaying) the time-arc as a function of the azimuth, with another design.*

Draw a circle and divide it into four quadrants, each being divided into 90 *p. 167*
equal parts. Trace imaginary lines from the rising amplitudes at both solstices to the centre. Construct the day-circles of the zodiacal signs as you constructed them on the astrolabe.[1] Place the ruler and at the centre and upon the azimuth corresponding to a specific time-arc at both solstices, and mark <the intersection of> the side of the ruler with the day-circles of Cancer and Capricorn. Place one leg of the compass on the meridian line, and join both marks with the other leg, between the larger and smaller day-circles: these will be the arcs[2] of time-arc. Number them. On each day-circle write (its) name at the left and at the right. The construction is completed.

With this circle you can also find the time-arc, provided a gnomon of indeterminate length is set at the centre, on the condition that it be on a flat ground. Sometimes the gnomon can be fixed, sometimes transportable, I mean movable at any (required) time.

{*Diagram*}

Diagram of (the sundial displaying) the time-arc as a function of the azimuth for latitude 36°.

<Text in the diagram:> East, West. – (Zodiacal signs).

[1] Spelled *al-skndrī*.

[2] The 'Old Mosque' of ʿAmr ibn al-ʿĀṣ (d. 43 H [= 664]) in Fusṭāṭ is the first one to have been built in Egypt (see *EI*[2], II, p. 958).

[1] I.e., according to stereographic projection in the plane of the equator. On this instrument there are day-circles for each zodiacal signs, whereas on an astrolabic plate only the tropics and equator are drawn.

[2] These are actually curves, but their approximation by means of circular arcs is rather satisfying.

86 *On the construction of the universal arc of the* ʿaṣr *on the horizon, called the 'hoof' (ḥāfir*[1]*).*

p. 156 Trace a circle that you divide into 90 equal parts. Assume a small vertical gnomon, such that the shadow at the *ʿaṣr* remains confined inside the circle up to a certain shadow length of your choice. Trace the lines of the meridian altitude (from the circumference) to the centre of the circle. Divide that gnomon into twelve parts: set this as a scale (for the construction). In terms of these parts open (the compass) to the shadow of the beginning and end of the *ʿaṣr* if you choose (it to be so). Place one leg of the compass at the centre and the other one where it cuts the line of the meridian altitude for that shadow of the *ʿaṣr*. Once you have marked the lines of meridian altitude with the marks of the beginning and end of the *ʿaṣr*, join them (to form curves) which will be the desired curves of the *ʿaṣr*. Write their names on both of them. The construction is thus finished. If you want to make the arc of midday, mark each line of meridian altitude with the measure of its midday shadow, and join these marks: this is what you desired.

Be aware that it is not possible to determine universal (quantities) other than the sixth (hour) and the arc of the beginning and end of the *ʿaṣr*, except if some other element is present, be it (determined) either by a sine (instrument) or by calculation, or be it (determined) by a good approximation, specifically for the inhabited latitudes and for timekeeping with the sun.

{*Diagram*}

<Text in the diagram:> Centre. – Arc of midday, for all latitudes. – Arc of beginning of *ʿaṣr*, for all latitudes. – Arc of beginning of *ʿaṣr*. – Arc of end of *ʿaṣr*, for all latitudes. – Arc of end of *ʿaṣr*.

87 *On the construction of the universal arc of the* ʿaṣr*, movable on a vertical surface, with a fixed gnomon.*

p. 174 We had constructed it on a board of wood, but it can be made on a plate of brass. By making its width equal to its length, the arc of the *ʿaṣr* will be such that it becomes nearly a quarter circle. Divide it (along its width) with the meridian altitudes, from 1° to 90°. Trace the lines of meridian altitude and mark the horizon and the pole (*watad*). Place one leg of the compass at the intersection of the horizon with the meridian altitude line and the other one where it cuts the meridian altitude line which is underneath the centre, that is, the location of the head of the gnomon. Divide this opening (of the compass) into twelve parts, and in terms of those parts open (the compass) to the vertical shadow of the *ʿaṣr*. Place one leg of the compass at the intersection

[1] There seems to be a confusion here between حافر ('hoof') and حلزون ('helix'), as the instrument should be called, following al-Marrākushī, II.2.2.

of the meridian line with the horizon and make a mark with the other leg upon that meridian altitude (line): this will be a point of the *ʿaṣr* arc.

If you want the arc of midday, open (the compass) to the vertical midday shadow and place one leg of the compass at the intersection <of the horizon> with the meridian altitude line and the other one where it cuts the meridian altitude line: this gives a point of the midday-line. <...> Join them as straight lines: these <...> arc of the *ʿaṣr*. You might want that this quarter circle[1] be perforated (*makhrūq*) or not;[2] that is, it should be a flat piece of brass or wood.

{*Diagram*}

<Text in the diagram:> Centre. – Gnomon length. – Arc of the beginning of the *ʿaṣr*, universal, for all latitudes.

88 *On the construction of the 'hoof' (*ḥāfir*) on which the* ẓuhr *and* ʿaṣr *are traced as complete circles.*

(The surface of this instrument) is movable on the plane, whereas its gnomon is fixed. To construct it, trace a circle and divide it in two halves. Trace a straight line passing through the centre and divide this line by the maximal shadow of the *ʿaṣr* at the solstices. Take twelve of these parts: this will be the length of the gnomon. Also in terms of these parts, open (the compass) to the shadow at the beginning of the *ʿaṣr* for Capricorn. Place one leg of the compass at the intersection of the line with the circle and the other one where it intersects it: this will be the position of the 'centre' of the gnomon.[1] In terms of the parts first (mentioned) open the compass to the shadow of the *ʿaṣr* at each zodiacal sign. Place one leg of the compass at the 'centre' and the other one where it cuts the circle, (and make a mark on its circumference) at the left and at the right: these are the marks of the zodiac. Trace straight lines that connect them to the centre (of the gnomon) and write between them the names of the signs. On the other circle, write 'arc of the beginning of the *ʿaṣr*'. Open (the compass) to the gnomon length, and place it (i.e., one leg of the compass) at the intersection of the zodiacal line with the circle and the other leg where it cuts this line: this will be the mark of midday. Do this for all zodiacal signs and join them as a complete circle, or (join them) pointwise (as a smooth curve). *p. 157*

{*Diagram*}

Diagram of the hoof for latitude 36° north.

[1] This probably refers to the *ʿaṣr* curve, which is shaped like a quarter circle.
[2] I.e., the extra portion of the board or plate outside of the *ʿaṣr* curve can be cut out.
[1] I.e., the base of the gnomon.

<Text in the diagram:> Centre. – Gnomon length. – Circle of the beginning of *ʿaṣr*, for all horizons with latitude 36°. – Circle of midday, for all horizons with latitude 36°. – (Zodiacal signs).

89 *On the construction of the arc of the* ʿaṣr *which is a complete circle.*

p. 170 Trace a circle and divide it into four parts, each quadrant having 90 of these parts. Place the ruler at its centre and at the azimuth of the *ʿaṣr* (at one of the solstices or at equinox) in terms of these parts. Open the compass to its horizontal shadow, and place one leg of the compass at the centre and the other one where it cuts that azimuth line: this is a mark for the *ʿaṣr*. Repeat the same (operation) (for the other zodiacal signs) and join (the marks) of the arc of the *ʿaṣr* (to form) a complete circle. Then fix that circle in relation to (*min*) the first circle. (You can do this) according to this procedure for any latitude you want, but it is only possible for latitudes greater than the obliquity of the ecliptic. God knows best.

{*Diagram*}

Circle of the arc[1] of the beginning of the *ʿaṣr*, for latitude 36°.

<Text in the diagram:> Centre. – Gnomon length. – Meridian line. – Eastern line. – Western line. – Circle of the beginning of *ʿaṣr*, for latitude 36°.

90 *On the construction of the cones, movable like the conical sundials (*makāḥil*), the conical gnomons, and the like.*

p. 150 Determine the inclination of that cone: to find its inclination, open the compass to the radius of the largest circle of the cone, and subtract from it the radius of its smallest circle. Open the compass to the difference and divide the height (*ṭūl*) of the cone by it, assuming that its height is divided into twelve equal parts. What remains from this opening will be a horizontal shadow. Take its (corresponding) altitude: this will be the complement of the inclination of that cone. Keep it in mind.

Assume that its thick (side) is at the bottom.[1] This is the one that lays on the ground. Add 90° to the complement of the altitude of that hour (you want). Subtract from the sum the complement of the cone's inclination. If the difference is smaller than 90°, take its horizontal shadow: this will be (the length of) the shadow of that hour underneath the base (*markaz*) of the gnomon of the cone. If the difference is larger than 90°, subtract it from 180°, and take the shadow of this difference: this will be the shadow of that hour (falling) above the centre.

[1] I.e., the circle of which a portion coincides with the arc.

[1] I.e., the truncated cone is standing upward on its base.

Once you have determined the shadows of the hours at the solstices,[2] open the compass to (these quantities), and place (one leg) at the location of the gnomon and the other one where it cuts the day-line of that zodiacal sign. It is necessary to divide the largest and smallest circumferences into twelve parts each, following the number of zodiacal signs, or into six parts. Once you have marked the hours on each day-line, join (these marks to form) the hour (curves), after you have traced the straight day-lines. Write the hours on them and the names of the signs.

If its thick (side) is above,[3] which means that it is suspended by a thread, then subtract its inclination from the complement of the altitude of the hour. Take the horizontal shadow of the difference: this will be the shadow of that hour, always (falling) underneath the centre. If its inclination is larger than the complement of the altitude of the hour, then be aware that it is not possible for the shadow of that hour to fall on that cone.

Know that the distance between the 'centre' and the 'horizon' corresponds to the (horizontal) shadow of the complement of the inclination.

As for the length of the gnomon which must be placed on the cone, one (first) has to divide the cone, that is, its inclined side should correspond to the quantity of the largest shadow of the hours. Take twelve of these parts: this is its length on the suspended (*al-muʿallaq*) cone. As for the upward (*al-qāʾid*) cone, one has to divide its length by the amount of the sum of the complement of its inclination and the largest shadow of the hours. From these (parts) take twelve: this will be its length.

Likewise if you want to make the altitude (circles) on the side of the cone, add the altitude to 90° and subtract the inclination of the cone from the total,[4] in case its thick (side) is at the bottom, and subtract its inclination from the complement of the altitude when its thick (side) is at the top. With the rest, do as we mentioned previously in order to obtain the desired result.[5]

{*Diagram*}

Diagram of the suspended cone, whose thick (side) is at the top and whose thin (side) is at the bottom, for latitude 36°.

<Text in the diagram:> Gnomon length. – (Zodiacal signs). – For the rest of the hours it is not possible that (their shadows) fall on the day-line of Cancer.

{*Diagram*}

Diagram of the (upward) cone on a plane surface, whose thin (side) is at the top, and whose thick (one) is at the bottom.

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[2] In fact they should be determined for all zodiacal signs!

[3] I.e., if the cone is upside-down.

[4] This is only true when the shadow falls above the gnomon. When the shadow falls underneath one should subtract the altitude from 90° and add the sum to the inclination of the cone.

[5] I.e., take its horizontal shadow.

<Text in the diagram:> Centre of the 'horizon'. – Length of the gnomon of the upward cone. – (Zodiacal signs). – Its hours for latitude 36°.

91 *On the construction of the base (*maḥilla*) of the ventilator (*bādahanj*).*[1]

p. 222 (This chapter includes a discussion of) its (different) names, the quantity of the good (north) winds (*al-hawāʾ al-ṭiyāb*) and that of the bad winds (*al-hawāʾ al-mafsūd*) (measured) on the horizon circle for that latitude. (The ventilator) has four names: the *furātī* (i.e., related to the Euphrates), the *mujannaḥ* (i.e., 'winged'), the *killī* (i.e., shaped like a veil) and the *ʿādilī.* The *furātī* stands (perpendicular) to a flat surface, whereas the *mujannaḥ* stands (perpendicular) to a surface that is 'winged' like the wings of a bird. The *killī* is (i.e., 'stands on' ?) the sloped surface. And the *ʿādilī* is the one that is on the side of a wall.

If you want to construct it, you have to trace a complete circle and to divide it into four quadrants. Trace a line from the rising amplitude of Capricorn to the setting amplitude of Cancer for that location. This will be *maḥilla* of the ventilator for locations that are far from the sea. <For locations that are near to the sea> such as Alexandria, Damietta, ʿAydhāb, Jedda and similar localities <the ventilator must be facing the sea.>[2]

Once you have made the *maḥilla* of the ventilator as I just explained, trace a line from the eastern point to twice (the value) of the rising amplitude of Capricorn: this will be the position of the closed (side). Then trace a line from the western point to twice (the value) of the setting amplitude of Cancer: this will be the position of the opened (side). The whole of the quantity of the good wind (measured) on the (horizon) circle is of 1[5]3°;[3] that of the bad wind (measured) on that circle is of 207°. We have divided one of these lines by the length of the *maḥilla* of the ventilator, and this represents one fourth of it. Be aware that the *maḥilla* (corresponds to) its length, the opened (side) (corresponds to) its width on the west side and the closed one (corresponds to) its width on the east side.

If you want to determine this by calculation, then divide its width by its length and take the sine of the rising amplitude of one of the solstices for that location, e.g. 27;44° for latitude 30°. We keep this in mind. Then we add the rising amplitude 27;30° to 90°, and the sum is 117;30°. We subtract from this twice the rising amplitude, that is 55°, and there remains 62;30°, of which we take the sine, and we get 53;[1]3°.[4] We double it and we obtain 106;26, which we divide by the quantity first kept in mind: there results 0;15,38°, which is a quarter of the length, and this is (roughly) equal to one quarter of a *qirāṭ*

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[1] The text of this chapter has been published in King 1984, pp. 128–129 (text), 109–110 (translation).

[2] I reproduce here the emendation proposed by King, *ibid.*, p. 109.

[3] The text has 183.

[4] The text has 53;53°.

of length (?? *maḥbūran*). Divide the *maḥilla* of the ventilator into 24 equal parts, and take six *qirāṭ*s and a quarter: this will be the width of the ventilator.

I have never seen anything about this method (among the writings) of those excellent scholars who preceded me. And I do not know anybody who has mentioned it. Anyone who wishes (to make a ventilator in an) accurate (manner) has just to follow what we have explained. Understand this and you will get it right.

{*Diagram*}

<Diagram of the ventilator.>

<Text in the diagram:> Base of the ventilator for latitude 30°; this is its back which is closed. – Closed. – face of the ventilator, which is open. – Open. – South, east, north, west. – First limit of the good winds *al-tiyāb*. – Last limit of the good winds. – First limit of the bad winds (*al-marīs*).[5] – Middle of (the wall facing) the bad winds. — Last limit of the bad winds.

92 *On the construction of the universal arcs of the* ʿaṣr *in a movable way, whilst its gnomon is fixed on it.*

We have constructed it on a board of wood. If you want that, take a plane *p. 174*
board and divide its width by the meridian altitude, from 1° to 90°. Trace the day-lines of the meridian altitudes, if you like at each 10° or 5° or otherwise. It is still better (to do it) at each degree, if there is enough space on it. Because if it is (divided) at each degree, then all of the meridian altitude lines (are present). Then number each day-line. Divide one of the day-lines into 30 parts. From these parts take a unitary part: this will be the gnomon length. It is actually your choice whether you want more or less than 30 parts. But if there are more than this, the operation with it (will depend on) the maximal shadow with which we have divided it.

Open (the compass) to the gnomon length, and place one leg of the compass on the horizon at the 90°-day-line and the other one where it intersects the line of the pole (i.e., the gnomon), and trace a straight line parallel to the horizon. Then place one leg of the compass at the intersection of the pole with the 90°-day-line and the other one at the intersection of each day-line. Divide this opening (of the compass) into twelve parts. In terms of these parts open (the compass) to the vertical shadow of the *ʿaṣr* for that day-line; place a leg (of the compass) at the intersection of the day-line with the horizon and make a mark on the day-line with the other leg. Continue to do that until the marks for the day-lines are completed. Join them as individual curves, pointwise or not: this will be the arc of the *ʿaṣr*. If you want to carve out the path of the arc,[1] (you can), but you do not have to. Be aware that the position of the

[5] These are the hot winds from the south.

[1] Literally, 'to make a hole where the arc falls'.

centre of the gnomon is the position of intersection of the 90° day-line with the horizon.

It is not necessary that a universal form be constructed other than the arc of the *ʿaṣr*, either horizontal or vertical. For some people will say: "The six hours, or the hours of the alidade, or of the horizontal sundial, which depend upon the meridian altitude, and which are for a horizontal sundial for latitude 0°, (or) the hours of the sine quadrant for which (some people) decided that each 15° should be one hour, (or) even the table in which the altitude at the universal hours is written in a very carefully done way, all of these are (found by) approximation, for timekeeping with the sun, and for the inhabited latitudes in particular. Anyone who takes some (universal) form among those mentioned may add a supplementary element to it, (taken) from another (non-universal) instrument of a complete design." Yet he is mistaken. Indeed, an instrument of complete methods does not need anything else. Likewise calculation: if one adds it to any of the instruments, he will (again) be in error.

You should know that this science is divided into three parts: calculation, geometry and instrumentation. Each of them has its individual methodology. For when two of them are being mixed, then each of them becomes deficient. Geometry and instrumentation have nothing to do with calculation. And only a small part of calculation has do to with geometry, for example the duration of the hours on some of the constructions and some of the instruments for specific (latitudes). Likewise some calculation can be associated to geometry, such as the solar longitude and its equation. (One can add to) universal instruments (quantities) like the durations of the hours or the oblique ascension or anything similar to that. There is nothing at all that has any association with calculation. For this reason (calculation) is the most noble and the best of these three divisions (of this science).

{*Diagram*}

Diagram of the universal *ʿaṣr* for all latitudes.

<Text in the diagram:> Centre. – Gnomon length. – Universal midday curve.[2] – *ʿAṣr* curve.

93 *On the construction of the sundials on the fixed columns, like the columns of mosques and other (buildings).*[1]

p. 196 Trace a circle on the ground and determine the cardinal directions. Place the ruler at the centre of that circle and at the rising amplitude of one of the solstices.[2] Mark the intersection of the side of the ruler with the base of the

[2] Literally 'line'.

[1] This chapter should in fact occur later, once the procedure for constructing vertical declining sundials has been presented (cf. Ch. 109).

[2] This has to be the winter solstice, since with the the shadow of the rising sun cannot fall on the column at summer solstice.

column and keep it. Then place the ruler at the centre and on the meridian line,[3] and mark again its intersection with the base of the column. Keep it. If you cannot join (the ruler with) the base of the column, then trace a circle different than the first one, and continue to trace circle after circle until the side of the ruler does intersect the base of the column, in such a way that it is not possible to have its name (??) on it, or have it go outside of it. Keep these two marks, which are the marks of the rising amplitude and of the meridian line. Divide the (arc) between both marks in two halves at the base of the column along a perfect line: this is the point of the vertical projection of the base of the gnomon, from which a plumb-line is falling along the column. This is the location of the gnomon. Open the compass to the distance between the centre of the circle and the vertical projection of the base of the gnomon: this will be the gnomon length, which is set on the horizon. Place the ruler at the centre and at the azimuth of each hour you want, and mark the intersection of the side of the ruler with the base of the column: this is the vertical projection of that azimuth, on which a plumb-line is falling. This is the line of the 'distance' of the hour. Open (the compass) to the distance between the centre of the circle and the mark of the 'distance' of the azimuth line, which is on the base of the column. Divide this opening into twelve parts, and assume these (lengths) as 'bases' (i.e., gnomon lengths). In terms of these 'bases' open (the compass) to the vertical shadow of the hours. Place one leg of the compass at the intersection of the azimuth line with the horizon, and the other one on the line of the distance of the hour. Make a mark: this is a point of the hour (line) on the face of the column. Do the same for the solstices, join the day-lines and the hour-lines. Number the latter and write the names of the signs on the former.

Six of these hours 'operate' from the beginning of daylight to midday, and are drawn on the eastern (side of) the column; six other 'operate' from midday to the end of daylight, and are (drawn) on the western (side of) the column. If you want, you may add to these six hours the arc of the *ʿaṣr*. If you want to make the azimuth lines, draw the straight lines of the distances at each 10°, or otherwise. If you want to make the altitude lines, divide into twelve parts the line that goes through the centre of the circle and the line of distance that has been marked at the base of the column. In terms of these parts, open (the compass) to the vertical shadow for the values of the altitude, at each 6° or otherwise. Number the azimuth and altitude lines. The construction is complete.

If (the instrument) has not been made according to the conditions mentioned, then the construction is faulty. I have found the construction of (certain?) (sundials on) columns to be different from what we have explained: it is again faulty (and) inexact. Whoever prefers faultiness over exactness should

[3] I.e., on the mark indicating the south on the circle drawn on the ground.

look attentively at the hours at the limits of daylight close to sunrise or sunset (and he will find that they are only given) approximately. The maker should be ashamed of its construction if it is faulty, and he should look (at it?) when it is correct. Some people are completely at lost when it comes to the construction (of such sundials). For they do not possess the method that leads to the truth. I have been able to examine (such sundials) by myself on columns in Cairo, where (they are) faulty, in particular when it is possible to see the shadow of the gnomon at the limits of daylight: (such sundials can be) in error by about an hour.

If the column is conical, then do what has been explained for the cones, after you have marked the locations of the shadows of the hour, as I have explained to you in relation to the obliquity of the cone. Fix the shadow on the line of the 'distance' on the column. If its thick (side) is above, then mark the distance of the hour, provided its falling on the column is possible. And if not, then do as previously explained for (such) cones.

{*Diagram*}

<Text in the diagram:> The face of the column and its hours from sunrise to sunset. – The back of the column and its hours from midday to sunset. – Circle for finding the cardinal directions. – Meridian line. – Line of the rising amplitude of Cancer. – Mark of the meridian line on the cone. – Mark of the horizon of Cancer on the cone. – Centre of the gnomon. – Gnomon length. – For latitude 36°.

94 *On the construction of the hours of the portable columns with movable gnomons, from which the rest is being suspended.*

p. 197 Determine (first of all) the cardinal directions. If you want that, divide the circumference of the column into 360 parts, and trace the meridian line and the east (-west) line. Mark (the circumference) according to the azimuth of the hour and its direction.[1] Let a plumb-line fall down from this mark (along the cylinder). On the plumb-line, mark the vertical shadow of the hour, in terms of the parts of the length of the movable gnomon. Once you have marked all of the hours, join the day-lines and write on them the name of its zodiacal sign. Do that for the solstices and join the hours with straight lines. Assume the gnomon to be located (perpendicularly to) the column at the 'horizon'. (Some people) draw that on the face of a (cylindrical) box (*ʿulba*), but it can (also) be drawn on a smaller box (*ḥuqq*)[2]. Write on it the terrestrial latitude for which the construction is done. Sometimes it is done in terms of the zodiacal signs, sometimes in terms of the meridian altitude, for a known terrestrial latitude.

[1] I.e., take the quadrant of the azimuth into account.

[2] Kazimirsky gives the definition of a *ḥuqqa* (pl. *ḥuqq*, *ḥuquq*, *ḥaqāq*, *ḥuqūq*, *aḥqāq*; in Middle Arabic, however, the singular is *ḥuqq* – see Dozy, *Supplément*, s.v.; cf. Hill 1985, p. 144) as a "petite boîte (qui peut entrer dans le علبة , comme celle-ci peut entrer dans le صندوق)"

Be aware that this figure cannot be reproduced on this page, because the page is a flat surface, whereas the column is cylindrical, so that it is impossible to represent it. If we had represented it on the page, it would have produced a distortion of its day-lines. Whoever wants to construct it just needs to know what we have mentioned.

95 *On the construction of the* Fazārī *balance.*

Take a (piece of) wood, thick in all four sides and perfectly solid (*ṣaḥīḥat al-badn*). Divide it along its length into any quantity you want. The best is to divide it into 144 (parts). Number them. Its first (i.e., one of its ?) vertical side is divided into twelve parts, and the universal hours are written on its side. They are not exact, but it is necessary that you write the midday shadow of each zodiacal sign for this latitude on its side. On its side the hours specifically for the inhabited latitudes — that is the seven climates – are made; the construction of these hours has already been mentioned before. These (hours) follow a very good approximation. We have not mentioned this balance, except for its being a very ancient instrument. It is a shadow instrument. The shadows are mentioned in the preceding tables, according to what (? *mimmā*) we assumed about (the instrument). *p. 222*

{*Diagram*}

Diagram of the *Fazārī* balance.

96 *On the construction of the bracelet dial.*

This is the one which is a complete circle of perfect circumference. Divide its circumference into 360 equal parts and take 30 of these parts, starting at the suspensory apparatus: this will be the position of the hole into which the rays enter as you take the altitude. Make a mark on (the point corresponding to) 30° in the opposite direction, (point) which is facing the hole: this will be the position of the 'horizon'. Place one leg of the compass at the entrance point of the rays and the other one at the 'horizon'. Trace a quarter circle connecting it to the (line of) vertical projection of the ray (*masqaṭ ḥajar al-shuʿāʿ*).[1] Divide that quadrant into 90 (equal parts). Place the ruler on the altitude of that hour (you want), counting from the 'horizon' on the outer scale of the quadrant mentioned, and upon the entrance (point) of the rays. This will give you the intersection of the ruler with the desired day-circle.[2] Make a mark on it, which will be the mark of the hour. Do that for (each of) the day-circles you want. *p. 142*

[1] See n. 5 on p. masqathajar.

[2] Najm al-Dīn omits to describe the construction of the day-circles: from the illustration we can see that, if we represent the inner surface of the ring in two dimensions as a long rectangular band, these lines will be equidistant, parallel lines drawn longitudinally on it.

When you have completed the marks of the hours, join them and number them. Write on each day-circle the names of its two (corresponding) zodiacal signs.

There are people who make it in both directions, whereby the entrance of the (solar) rays is (also on) the horizon, so that the hours of the first half of daylight are connected (?) with those of the second half of daylight.

The construction of the bracelet is thus completed, God Almighty willing.

{*Diagram*}[3]

Diagram of the bracelet for latitude 36°.

<Text in the diagram:> Entrance of the ray. — Falling of the ray. — Altitude arc of all hours for all zodiacal signs. – Cancer, Aries, Capricorn.

<Remark:> This arc is one third of the circle of the bracelet. Sometimes six more hour-lines are made on it, and sometimes there is no such construction on it, as on this picture.

97 *On the construction of the 'locust's leg', as a function of the meridian altitude, for a specific latitude, and for any location you want.*

p. 147 Take a flat board and divide it according to the vertical shadow of the maximal meridian altitude, into equal parts. Number the meridian altitudes after you have traced their straight lines. Divide one of the lines by the maximal vertical shadow for that latitude, and repeat this (operation). Join the marks of the hours. Write the terrestrial latitude for which the construction is done. Understand this and you will get it right, God Almighty willing.

{*Diagram*}

Diagram of the 'locust's leg' composed of the meridian altitude for latitude 36°.

<Text in the diagram:> Centre. – 'Horizon' line. – Gnomon length. – For latitude 36°.

98 *On the construction of the 'locust's legs', as a function of the solar longitude, for a specific latitude, and for any location you want.*

p. 146 Take a flat board and divide it into twelve parts. Trace straight lines (perpendicular to these marks) and write the names of the zodiacal signs on them.

Divide one of the lines according to the vertical shadow of the maximal meridian altitude for that latitude. Assume this quantity (to measure) twelve (parts): this will be the gnomon length. Make it the scale (for the construction), from which the amount of the vertical shadow of the hours at the beginning of the zodiacal signs with the longest shadow will be measured. Place

[3] See Plate 11.

one leg of the compass at the centre and the other one where it cuts the 'pivot line'. You should know that each day-line has (a hole for) a gnomon (*kull madār lahu qāma*). Write the terrestrial latitude on (the instrument).

{*Diagram*}

Diagram of the movable 'locust's leg' composed of the solar longitude for latitude 36°.

<Text in the diagram:> Centre. – 'Horizon' line. – Gnomon length. – For latitude 36°. – (Zodiacal signs).

99 *On the construction of the stair-case sundial provided with steps and fixed on a horizontal surface.*

This is the one (in which), whenever an hour of daylight passes (before mid- *p. 208* day), the shadow of the gnomon falls by one step, and whenever an hour of daylight remains (before sunset), its shadow rises by one step.

Take a piece of flat marble. Let its thickness be of one ratio (? *nisba wāḥida*), or its height[1] be the same as the length of the gnomon you want (to use). Divide that gnomon into twelve equal parts. Determine the meridian line on a flat ground and mark (it) at the location of the gnomon. Trace a straight line for the azimuth of the fifth (hour) from the west and for the azimuth of the fourth (hour) from the east, at both tropics. Determine their shadows at these hours and trace straight lines as when you did the hours of the horizontal sundial. Know that the gnomon height (*qāma*) is the distance between the end of the gnomon and the thickness of the first (piece of) marble. Place the second (piece of) marble above the first one after you have determined the azimuths of the fourth and eighth (hours). Do as you did previously, from the east and the west. You should know that every time you place a piece of marble upon another one, the length of the composite (*murakkab*) (piece) decreases. It is necessary for the constructor to have adequate vision concerning it, because the person present can see what the absent one cannot. And it is not possible to represent it on paper, because it is step above step. When we have illustrated it on paper, it came out like the diagram of the *maknasa*, which (will) follow.[2] We will not repeat its depiction at all (here), because its representation depends on (?) the maker (*li-anna 'l-tashkīl bi-ghayr al-wāḍiʿ*). You should (furthermore) know that sometimes the steps are equal (in size) whereas the landings (*basaṭa*) are not, and sometimes both the steps and the landings are not equal (in size). It is (in such cases) not possible for them to be equal to each other, because the shadow of the first hour is larger than that of the second one, and that of the second one is larger than that of the third

[1] Literally, 'elevation'.
[2] The *maknasa* sundial is featured in Ch. 108.

one, and so on. If the sundial were (not fixed but) movable, then you would need to construct the day-lines.

100 *On the construction of the 'locust's leg' whose hour(-lines) are function of the altitude, for the zodiacal signs, and for any location you want.*

p. 139 Divide its width into six equal parts, and join them to a single point (by tracing lines converging at that point).[1] These will be the day-lines. Trace a quadrant divided into 90 (equal parts) and place the ruler upon the altitude (on the quadrant scale) at each hour and at the centre of the quadrant, which is the centre of the gnomon. Mark the intersection of the ruler with the day-lines. When the hours are completed, number them. As for the gnomon length, determine the vertical projection[2] of the sixth hour for each zodiacal sign, (by finding) the intersection of the thread with the horizon. Open the compass to twelve parts, and place one leg of the compass upon the mark and the other one where it cuts the pivot line: this will give you the gnomon length of that 'locust's leg'. It is fixed, not movable.

{*Diagram*}[3]

Diagram of the 'locust's leg' composed of the altitude of the hours. For latitude 36°.

<Text in the diagram:> Centre. – 'Horizon' line. – 'Vertical falling'. – (Zodiacal signs).

101 *On the construction of the* ʿaṣr *curve on horizontal sundials and on (other) instruments.*

p. 171 You should know that some people constructed astrolabes with many plates. On each plate the *ʿaṣr* curve is engraved (and the plates serve) for many latitudes. When you looked at the plates and you found them to be incorrect with respect to the *ʿaṣr* curve, correct (*raddid bihi ilā al-ṣawāb*) and erase the engraving (*wa-kashshit al-naqsh*), and fix it as I shall mention to you (?).

I have heard one eminent person in this field say that he found one of the manuscripts of the (treatise by the) eminent *Shaykh* Abū ʿAlī al-Marrākushī, in which the *ʿaṣr* curve is traced for a location with no latitude as a curve (incurved) towards the eastern side and composed of a single arc with a single centre. Perhaps we should think that this is due to the copyists.[1] As people say: "What is information without proper oral transmission?" For

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[1] The point of convergence is the upper-right corner, as can be seen on the illustration.
[2] See n. 5 on p. masqathajar.
[3] See Plate 10.
[1] Such a mistake indeed occurs in all copies of al-Marrākushī's *Jāmiʿ* known to me, and it can only be imputable to the author, not the copyists. See further the remarks in the commentary on p. 171.

what *Shaykh* Abū ʿAlī has designed is one thing, and the instruments in the manuscript is what he (i.e., the copyist) has drawn.

I needed to mention that for whoever wants to construct (the *ʿaṣr* curve). It is (as follows). If the terrestrial latitude is larger than the obliquity of the ecliptic, then the *ʿaṣr* curve is the regular one, having a single arc with a single centre which is in relation to a single direction. If the latitude is smaller that the obliquity of the ecliptic, then the *ʿaṣr* curve is composed of two arcs, each of them having his own centre, sometimes with a single direction on the side of its curvature, sometimes with two centres.

If you want to construct that on the (horizontal) sundials, identify the centre of the gnomon you want, and trace a circle around its centre, which you divide into 360 parts. From these parts take the azimuth of the *ʿaṣr*, counting from the eastern line, at the solstices and at the zenithal degree (*darajat al-musāmata*).[2] Determine[3] the azimuth at the *ʿaṣr* for a longitude between the zenithal degree and Capricorn.[4] Determine their shadows. Do exactly as you made the hour-lines of the horizontal sundial, and join the three marks which are those of Capricorn, Libra, and the degree of the zodiac that is in-between, namely the opposite of the zenithal degree. This will be the first arc. Join the three other marks, namely the marks of Aries, of the zenithal degree – which is the one whose *ʿaṣr* altitude is 45 degrees – $<$and that of Cancer$>$. Join them with the opposite of the zenithal degree. Mark (them) over the hour-lines or over the altitude circles. Join them as a single arc. Join the three other marks as a single arc (as well).

You thus have constructed the arc of the *ʿaṣr*. We have imposed to ourselves the duty of determining for the arc of the *ʿaṣr* an altitude and its azimuth and the direction of its azimuth for the zodiacal signs mentioned, in the assumed latitudes. They are placed in tabular form, and we have illustrated each of both arcs mentioned. We write the terrestrial latitude for which we have made the computation besides each of these arcs and on the table, in order to explain it and to make it easy to whoever wants (to achieve) the construction, according to what he wants, on the sundials or on (astrolabe-like) instruments or fixed on horizontal or vertical (surfaces).

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[2] I.e. the longitude of the sun when it culminates at the zenith, corresponding to $\delta(\lambda) = \phi$.

[3] The rest of this paragraph is rather confused; I have not attempted to correct it beyond a few obvious emendations. See also the commentary.

[4] The text has ‘equinox’.

TABLE T.15.

Table to make the *ʿaṣr* curve for a location with no latitude, for a horizontal or vertical (sundial), or for (astrolabic) instruments									
Cancer		Taurus 15°		Aries		Scorpio 15°		Capricorn	
az	*u*	*az*	*u*	*az*	*u*	*az*	*u*	*az*	*u*
26;00 N	17;15	20;51 N	15;32	0;00	12;00	20;51 S	15;32	26;00 S	17;15

Table to make the *ʿaṣr* curve for a latitude of 12°, for a horizontal or vertical (sundial), or for (astrolabic) instruments									
Cancer		zenithal degree		Aries		opp. of zenithal degree		Capricorn	
az	*u*	*az*	*u*	*az*	*u*	*az*	*u*	*az*	*u*
21;00 N	14;23	5;00 N	12;00	9;52 S	14;33	23;44 S	17;21	35;43 S	20;54 S

{*Diagram*}

Forms of the *ʿaṣr* curves for latitudes smaller than the obliquity of the ecliptic.

<Text in the diagram:> Gnomon length for a place without latitude. – Meridian line for a place without latitude. – Cancer, opposite of zenithal degree, Aries, zenithal degree, Capricorn.
Arc of the *ʿaṣr* for latitude 12°. – Gnomon length for latitude 12°. – Meridian line for latitude 12°. Cancer, Aries, opposite of zenithal degree, Capricorn.

102 *On the construction of the horizontal sundial (*basīṭa*) without having to place the ruler on the azimuths of the hours or (to use) their horizontal shadows.*[1]

pp. 190, 202 This follows the (general) method (used for constructing) inclined sundials. A horizontal sundial is indeed (like) a vertical sundial (parallel) to the east-west line with an inclination of 90° towards the north.

If you want that, determine its table, which consists in finding the 'distance' and the 'auxiliary shadow' on the vertical sundial (parallel) to the east (-west) line, on the northern or southern face (and in arranging these quantities in a tabular form). (To find the auxiliary shadow on the horizontal sundial), determine the altitude that corresponds to this 'auxiliary shadow' (on the vertical sundial) and take its vertical shadow. (But in the general case of an inclined sundial) you would add (this altitude) to the inclination of the sundial plate (*mayl al-rukhāma*), or you would subtract it from the inclination of the sundial plate, and you would then take the <horizontal> shadow of the (sum or) difference. <But when the inclination of the sundial plate is 90°,> there results a vertical shadow (instead). For that reason we mentioned it[2] before considering the inclination of the sundial plate. This vertical shadow

[1] Logically this chapter should occur later in the treatise, since it presupposes a knowledge of the construction of vertical and inclined sundials.

[2] I.e., the procedure for the horizontal sundial.

will give you the < auxiliary > shadow of that hour on the horizontal sundial. Then consider whether the azimuth of the hour is northerly, (in which case) its shadow will be underneath the centre, and if its azimuth is southerly, then its shadow will be above the centre. Keep this in mind. We have only mentioned the azimuth here because its (the sundial's) inclination is 90°. And we do not distinguish 'above it' from 'underneath it' except with respect to the direction of the azimuth for this particular inclination.

For the 'distance', divide the shadow of the hour, which you kept in mind, by the Cosecant of the inclination, which is twelve. Multiply the result by the 'distance' of the hour on the vertical sundial (parallel) to the east-west line. The product will give you the 'distance' of the hour on the (horizontal) sundial. If you want to construct all inclined sundials (*māʾilāt*) in the same way as you construct declining sundials (*munḥarifāt*), consider the (auxiliary) shadow of the hour: if it is above the centre, then subtract it from the tangent of the inclination of the sundial plate, and if it is underneath it, then add it to the tangent of the inclination of the sundial plate. The result will be the shadow of that hour (measured) from the 'horizon'. And the 'distance' is (found ?) on its own (*ʿalā ḥālatihi*). Place it in a tabular form (so you can) make (the sundial) from it in the same way you make declining sundials.

Know that the distance of the centre from the 'horizon' is the tangent of the inclination of the sundial plate. If you want the distance of the centre from the 'horizon' (on the horizontal sundial),[3] multiply the 'distance' of the first (hour) of Capricorn by itself and multiply its horizontal shadow by itself; subtract what results of multiplying the 'distance' (by itself) from the result of the multiplication of the horizontal shadow (by itself). Take the square root of the result: this will be the distance of the centre from the 'horizon'. In this book of ours we have not mentioned square roots except at this place.[4] When the sundial is inclined by 90°, the tangent of its inclination is infinite: (for that reason) we imagined in place of it (an alternative 'horizon' found by) the method of multiplication and square root. And if you want to consider neither multiplications nor square roots, then trace a straight line, and divide it with the compass by the 'distance' of the hour. Place on (one extremity of) it one side of the 'instrument with the right angle' (*al-zāwiya*) and trace along its other side a line of indeterminate length.[5] Open the compass to the horizontal shadow of the hour. Place one leg of the compass at the (other) extremity of the first line and the other one where it cuts the second line, and make a mark. Place one leg of the compass upon that mark and the other

[3] This 'horizon' – which has nothing to do with the real horizon, which projects to infinity on the horizontal sundial – designates here a line parallel to the east-west line which is tangent to the upper extremities of the declination curve of Capricorn. This line represents in fact the axis of the coordinate 'distance'.

[4] See p. 30 of the introduction.

[5] Literally "an infinite line". See n. 2 on p. 272.

one at the intersection of both lines: the resulting opening (of the compass) will correspond to the distance of the centre from the horizon of the inclined (sundial). I do not know a single person who has ever mentioned this method. However, the *Shaykh* Abū ʿAlī al-Marrākushī – may God have mercy upon him – mentioned for all inclined (sundials) a method which assumes (?) inclined sundials (*al-māʾilāt*) (having inclinations) between 89° and 45° – their method of construction being by the 'distance' and 'auxiliary shadow' – and sundials 'inclined upward' (*al-murtafiʿāt*) (having inclinations) from 1° to 45° – their method of construction being by the azimuth and the shadow.[6]

(The inclined sundials) have already been illustrated,[7] and some of them are facing the sky. We have not (yet) considered those facing the earth. This (was) a method of ours. May God in this (matter) provides inspiration during awakeness and during sleep.

TABLE T.16. Table of the horizontal sundial for latitude $<36^\circ>$

	Cancer		Capricorn	
hours	distance	shadow	distance	shadow
1	45;30	56;00	60;00	0;00
2	21;00	45;05	27;45	15;30
3	13;20	41;40	17;40	21;30
4	7;30	40	9;32	23;20
5	3;37	39;20	4;00	24;00
6	0;00	39;09	0;00	24;14
ʿaṣr	13;40	42;00	20;30	18;30
	shadow of the 6th hour of Aries 33;34		dist. of the *ʿaṣr* of Aries 18;19	
	dist. of the centre from the horizon 40;30		shadow of the *ʿaṣr* of Aries 33;34!!	

Picture of the table that is like the table for inclined sundials.[8] The construction (of a horizontal sundial) with it is like the construction of the inclined sundials. This kind of table is very much unlike the (standard) table for the horizontal sundial, of which it dispenses. God Almighty knows best.

[6] al-Marrākushī does indeed give procedures for constructing inclined sundials using both coordinate systems; however, he does *not* restrict their application to a certain range of inclinations. See Sédillot, *Traité*, pp. 338–341.

[7] In fact, inclined sundials are not featured before Chapter 108!

[8] The text has 'declining sundials'.

103 *On the construction of the hours of the basin which does not empty. The basin can be semicircular*[1] *or otherwise.*

If (its meridian) is semicircular, make its upper (side) a perfect (plane) so that it forms a perfect horizon. Divide the semicircle, that is, its inner part, into 180 (equal parts). Place one leg of the compass at the centre of the basin and the other one at the altitude of that hour (which you want to mark), after the circumference of its upper (side) has been divided into 360 parts. Let a plummet fall from that division corresponding to the azimuth of the hour, counting from the eastern point. Trace a straight line to the centre of the basin. Place the leg (of the compass) that is on the altitude of the hour upon the azimuthal line of the hour and (in this manner) make marks for all hours, join them and number them. Then, join the day-circles and write the names of the signs on them. *p. 208*

If it is not semicircular, like (in the case of) the bowl or the *kashkūl*, then we have invented for this a board of carved wood whose width is divided in two halves, which (corresponds to) the length of its gnomon. We have placed one leg of the compass at the side of the gnomon on that board and we have traced a quarter circle with its (other) leg, and we have divided it into 90 (equal parts). We have divided the circumference of the *kashkūl* into 360 (equal parts) and we have traced the lines of azimuths of the hours from this division to the centre of the bowl. This is the line of the azimuth of the hour. Then, we have placed the piece of wood in the middle of the bowl, and we have marked the altitude of the hour on the divided quadrant. We have pasted the piece of wood along the line of azimuth, and we have transfered the mark of the altitude of the hour to the body of the bowl: this is the location of the hour. When all (marks for the) hours are completed, join them; then, join the day-circles. The best construction has twelve day-circles, in order to determine with them the (cardinal) directions. Write the names of the signs on the day-circles. The construction is complete.

It is not possible to give an illustration on the page, because it (i.e., the basin) is hollow. Whoever wants to make it, let him ponder over what we have mentioned, God Almighty willing! Sometimes (this sundial) is made fixed, and sometimes it is movable. Be aware that the gnomon length is (the distance) from the centre of the piece of wood until its half.

104 *On the construction of the bowl placed upside-down, that is, the hours of the dome placed upside-down.*

Divide the circumference of the bowl or dome into 360 equal parts, and trace lines (from there) to the centre of the upper (side of) the bowl or dome. These *p. 208*

[1] ‘Hemispherical’ would be better, but the rest of the chapter suggests that this expression refers to the longitudinal cross-section of the basin (i.e., the meridian)

will be the lines of azimuth. If they are fixed (with the instrument), determine the (cardinal) directions, and if they are movable, there is no need for determining the directions. Place the ruler at the centre of the upper (side) of the dome and assume a gnomon. Place it on the ruler and for the gnomon length take the thickness of the ruler into account. Place a thread at the extremity of that gnomon after you have divided the ruler by the length of the base. Place the thread on the quantity of the length of the shadow of the hour you want, if the falling of the thread upon the dome is possible; if not, shorten the base. Continue to reduce the base or to augment it until the shadow of that hour will fall at the side of the dome. Place the thread on (the position of) the second, third, fourth, fifth and sixth (hours) and mark (them) on the dome at the falling of the thread on a single azimuth (line). When the marks of all hours are completed, place one leg of the compass at the centre of the upper (side) of the bowl or dome and the other leg upon the mark of that hour (you want). Move its leg that is on the mark until you place it on the line of azimuth of that hour: this will be the position of the desired hour. Join the hour-lines and the day-circles, and in the same manner the arc of the beginning of the *ʿaṣr*. Write on each (day-circle) its name. The construction is finished, God Almighty willing.

105 *On the construction of the ruler with which the altitude can be measured.*

p. 222 (The ruler) has the shape of one side of the 'instrument with the two branches' (*dhāt al-shuʿbatayn*) and its divisions are as the divisions of this side. Explanation thereof: divide the face of the ruler into 60 equal parts. Then divide the back of the ruler into 30 parts, being 25 parts of the divisions of its face. Set it (i.e., the ruler) according to the altitude, and mark the extremity of its position on the ground. Place the ruler on (this point) and stretch it as a straight line: (this is) the location of the thread.

Know that the maximal opening of this ruler (*nihāyat iqāmat hadhihi al-masṭara*) is a right angle, and this is at (any) time when the altitude is 90°. Know (also) that the minimal opening (*nihāyat busṭihā*) is (as its laying) on the ground at sunrise or sunset.

If you have set up a vertical scale (? *ʿūd*) or anything else, you have done what we have mentioned, you assume its divisions in an approximate way, and you have determined the altitude at that time, then that column <… >

You will find the altitude with this ruler at any time and for any latitude, expect at midday, unless its divisions are sufficiently numerous, say, at each minute or at each second, so that the altitude can be determined with it (even) at midday.

{*Diagram*}

Diagram of the ruler when the altitude is 60°.

<Text in the diagram:> Face of the ruler. – Back of the ruler. – Rest of the altitude (scale). – Aspect of the thread. – Aspect of the flat horizontal ground. – Mark of the head of the ruler upon the flat ground.

106 *On the construction of the flat conical* (sic![1]) *sundial (*al-mukḥul al-musṭaḥī*), being the one whose coneness [is such that its head has as many]*[2] *equal parts as its base, such as the columns, the small boxes (aḥqāq) and (larger) portable boxes (al-ʿulab al-naqqāla)], their gnomons being movable on them.*

Divide its circumference into six parts according to the number of zodiacal *p. 149* signs. Trace straight lines (from these divisions) and write the names of the signs on it. If you want divide it into twelve parts and write the name of (each) sign and its declination. Then, open (the compass) to the length of this *mukḥul* and divide it according to the hour with the longest vertical shadow. This may correspond to the sixth hour of Cancer for latitudes greater than the obliquity, (however) when it is smaller than the obliquity, it corresponds to the vertical shadow of some hours whose shadows are longer than the shadow of the sixth (hour) of another sign, be it Cancer or otherwise. When you have finished with the divisions, take twelve parts thereof, which will be the length of the movable gnomon on the side of the construction. Make it a linear scale (*masṭara*). From this scale, take the vertical shadow of (each) hour at the beginning of (each) sign you want, and place one leg of the compass at the base of one side of the day-line, and make a mark with the other leg on the day-line of that sign you want: this will be the location of the hours. Do this (operation) for all signs, and join (the marks of) the hours. Number them. If you want the arc of the *ʿaṣr*, do it according to its vertical shadow for all signs. Trace it pointwise (as a smooth curve) or through (piecewise) linear segments. If you want to make (markings for) the altitude, do (it) with the vertical shadow of that altitude, (for longitudes going) from one degree to eighty-nine. Number them. This completes the construction.

Be aware that some people make it in terms of the meridian altitude and label it 'universal'. But this is wrong. It is only necessary that it be written "approximate for inhabited latitudes only, (and for timekeeping) with the sun only". Or you make the day-lines up to the maximal meridian altitude of the sun at that latitude, (in which case) you write on it the latitude for which you have constructed it; (in this case) this (i.e., the markings) is accurate. This is the construction of the 'locust's leg' on a flat surface, I mean it has the shape of a flat board (drawn) on a sheet of paper (*nashra*) or on an instrument of flat form. Its gnomons are movable on the instrument.

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[1] *Read 'cylindrical'.*

[2] My reconstruction: the first line is partly illegible.

{*Diagram*}

Diagram of the conical *mukḥul* for latitude 36° north.

< Text in the diagram: > Temporal hours. – Length of the movable gnomon. – Slot of the movable gnomon, which is the horizon. – Meridian line. – *ʿAṣr* arc.

107 *On the construction of* [*the vertical sundial (parallel) to the meridian* . . .].

p. 192 This is (made) by means of the sundial table (*jadwal al-basīṭa*) with the azimuth and the vertical shadow. (On the vertical surface) trace the 'line of the horizon' (*khaṭṭ al-ufuq*) and from any point you wish suspend a plumb-line: this will give you the 'vertical axis' (*khaṭṭ al-watad*) and the position of the gnomon < will be its intersection with the 'horizon' >. Place one leg of the compass at the position of the gnomon and trace a semi-circle with the other leg, which you divide into 180[1] (equal parts). From these parts take the azimuth of the hour (you want), starting from the intersection of the vertical axis with that (semi-) circle. < Place one leg of the compass at the centre > and the other one where it cuts the (semi-) circle towards your left/north (*min jihat shamālika*), if (the azimuth) is northerly, or towards your right/south (*min jihat yamanika*), if the azimuth is southerly (*yamānī*). Place the ruler on it and at the position of the gnomon, and trace a radial line. Open the compass to the gnomon length you want, and place one leg at the position of the gnomon and the other one where it cuts the vertical axis. Make a mark and keep it. Trace there a straight line parallel to the 'horizon'. Place one leg of the compass at the position of this mark that was kept and the other one at the intersection of the radial line with the line parallel to the horizon. Place (one leg) with < this > opening < at > the position of the gnomon and the other one where it cuts the 'horizon line' in the direction of the azimuth of the hour. This will be the position of the 'distance' of the hour. Suspend from there a plumb-line: this will give you the line of 'distance' of that hour. Place one leg of the compass at the position of the 'distance' of the hour and the other one upon the mark that was kept. Then divide this opening into twelve parts, in terms of which you open (the compass) to the vertical shadow of the hour. Place one leg at the position of the 'distance' of the hour and the other one where it cuts the line of 'distance': this will be the position of the hour.

Do this for all hours at the beginning of (each) sign whose day-line is possible to be drawn within the limits of the sundial, towards left or right. Then join the (markings of each) day-line. For the sixth hour, which falls on the ground, take (the distance of) the vertical projection of the tip of the gnomon (*masqaṭ ḥajar mawḍiʿ al-murī*) down to the base of the sundial plate – which corresponds to its length – and divide it into twelve equal parts, from which

[1] The text has 90.

you take the horizontal shadow of the sixth hour (for each sign). Place one leg of the compass at the vertical projection of the tip of the gnomon (*masqaṭ ḥajar raʾs al-shakhṣ*) and the other one where it cuts the line of vertical projection (*sic*).[2] This will give you the desired result.

{*Diagram*}

Diagram of the vertical sundial (parallel) to the meridian line, for latitude 36° north.

<Text in the diagram:> Eastern face of the sundial. – Centre. – ‘Horizon’ line. – Gnomon length. – Point of vertical projection. – Line perpendicular to the ‘horizon’ (*bis*). – Arc of the beginning of *ʿaṣr*. – First, second, . . . , fifth, seventh, . . . , twelfth (hour). – Cancer, Aries/Libra, Capricorn.

108 *On the construction of the vertical sundial (parallel) to the meridian line, inclined towards the east and towards the west by (an angle of) 45°.*[1]

Open the compass to the (auxiliary) shadow of the hour on the vertical sundial pp. 201, 203, 207 (parallel) to the meridian (plane) which has been constructed before this, and know it. <. . . > Take its vertical shadow, which is the shadow of the hour above the centre if their sum (*sic*!) is greater that 90; and it is underneath the centre <if it is smaller than 90>. (In the former case) add it to the shadow of the inclination of the sundial plate. But if is underneath the centre, subtract the smaller (quantity) from the larger (one). <. . . >[2] the hour on the vertical sundial in the meridian (plane). The sum will be the ‘distance’ of the hour on the declining sundial. Be aware that this sundial is composed of two surfaces, one being joined <to the other>. The location of the horizontal gnomon (*al-shakhṣ al-munakkas*) is the rising- or (text: ‘and’) setting-point of Aries. Its length is the secant (lit. ‘hypothenuse of the shadow of the complement’) of the inclination of the surface.

<. . . > . . . known as the *maknasa*, and this is (constructed) by means of the vertical sundial (parallel) to the meridian. If you want to do this, take the parts of its gnomon and consider the corresponding altitude.[3] Add it to the inclination of the sundial plate and take <. . . . . . > the centre if their sum is smaller than 90°. If you want the ‘distance’, consider whether the shadow of the hour is above the centre, and (if it is the case) divide the rest by the Cosecant of the inclination of the sundial plate. Multiply the result of the division by the ‘distance’ of the hour (on the vertical sundial). You should know that the distance of the centre[4] from the ‘horizon’[5] is the shadow of the comple-

[2] This should rather be ‘the base of the sundial’.
[1] The text of this chapter is severely corrupt.
[2] The copyist left a blank space here. There is apparently another important lacuna in the text.
[3] I.e., $\text{arcCot}\, 12 = 45°$.
[4] I.e., the base of the gnomon perpendicular to the plane of the sundial.
[5] I.e., the gnomonic projection of the horizon on the sundial.

ment (i.e., the tangent) of the inclination of the sundial plate, and similarly (*wa-kadhā*) its length is twelve (parts) of the rule (used) in the construction of the other (sundial ?). (This composite sundial) works from sunrise to sunset. To find the length of the gnomon perpendicular to the ground, divide the width of the sundial by the Secant[6] of its inclination, and take twelve of the resulting parts: this will be its length.

{*Diagram*}

The vertical sundial (parallel) to the meridian line and inclined towards the east by 45°.

<Text in the diagram:> Line of the western horizon. – Centre of the horizontal gnomon. – Centre of the perpendicular gnomon. – The horizontal gnomon. – *ʿAṣr* arc. – Sixth, seventh, …, twelfth (hour). – Cancer, Libra, …, Sagittarius.

{*Diagram*}

The vertical sundial (parallel) to the meridian line and inclined towards the west by 45°.

<Text in the diagram:> Line of the eastern horizon. – Centre of the horizontal gnomon. – Centre of the perpendicular gnomon. – The perpendicular gnomon. – First, second, …, sixth (hour). – Capricorn, Aquarius, …, Gemini.
<Text in the diagram:> <……> on the line of the sixth (hour) at the intersection of the two faces (*bayn al-rukhāmatayn*).

109 *On the construction of the declining sundial (*al-munḥarifa*) without having to determine the declination, the gnomon length or its centre.*

pp. 195, 196 Draw a circle <on> the (perfectly) flat ground. Determine the cardinal directions and draw the meridian line and the east-west line. Determine the azimuth of the hour and its direction from the already mentioned horizontal sundial table (*jadwal al-basīṭa*). Place the ruler on this azimuth and at the centre of the circle, and make a mark at the intersection of the ruler with the wall, and keep it. Let a plumb-line fall (along the wall) above this mark and make a mark on the 'horizon' at the position of the plumb-line. This will be the position of the <mark of the 'distance'> for that hour. Know this. Then determine from the table mentioned the vertical shadow of that hour for this (particular) zodiacal sign. Place one leg of the compass at the centre of the circle and the other one upon the mark you have kept. Divide (the quantity of) each opening hence defined into twelve equal parts. With this opening (of the compass) take the vertical shadow, and keep it for when it will be needed with the inclined sundials.[1] Transfer the compass with this opening so that you

[6] The text has 'Cosecant'.
[1] Cf. Chapter 111.

place it on the mark of the ‘distance’ of the hour, and the other leg where it cuts the plumb-line (for this particular ‘distance’). This will be the position of that hour. Do this for Cancer and Capricorn, and join (the marks of) the hour (lines). Join (also the marks pertaining to) each of the two day-circles. For the day-circle of Aries, mark the intersection of the east-west line (on the ground circle) with the base of the sundial plate or of the wall, and let a plumb-line fall (thereupon). The place where the thread occurs on the ‘horizon’ will be the ‘horizon’ of Aries. For the midday shadow for Aries, divide the meridian line which is on the flat ground into twelve parts, and take in terms of these parts the vertical shadow of the sixth hour for Aries. < Transfer the compass with this opening by placing one leg at the intersection of the ‘horizon’ with the line of the ‘distance’ of the sixth hour, and the other one where it cuts this line, and make a mark: this will be the location of the sixth hour for Aries. > (Trace a line) from there which connects (it) to its ‘horizon’: this will represent the day-line of Aries. If you want to construct on them (i.e., the declining sundials) the declination curves of all zodiacal signs, construct them by means of the vertical shadow of the hours and of their azimuth.

{*Diagram*}

(Sundial) declining from the meridian by 50°. It is connected to the other declining sundial. For latitude 36°.

< Text in the diagram: > The south-western face. – Western line of the horizon. – Centre. – Gnomon length for this declining sundial. – Capricorn, Aries, Cancer. – Sixth, seventh, …, twelfth (hour). – *ʿAṣr*.

This (portion of) the page represents the ground for the sundial with declination 50°. – Meridian line. – Azimuth of the fifth (hour before sunset!) of Capricorn. – [Azimuth of the] {4th, 3rd, 2nd, 1st}[2] [(hour before sunset!) of Capricorn]. – [Azimuth of the] seventh (hour) of Libra. – Azimuth of the {eighth, ninth, tenth, eleventh} (hour) of Cancer. – Line of the setting amplitude of Cancer.

110 *On the construction of the ‘connected sundial’ (*al-mawṣūla*), which has three (different) shapes, one of them being this one, namely, (that of) the (sundial) whose declination is the complement of the declination of the other one..*[1]

This (first kind of connected sundial) is the one whose declination equals pp. 196, 205
the complement of the declination of the other one, that is, they stand at right angle (to each other); the inclination of the second one is greater than the complement of the inclination of the other one: it is (called) ‘opened’

[2] Written in Indo-Arabic numerals.

[1] I.e., the one featured in the previous chapter.

(*maftūḥa*) with respect to a right angle;[2] the inclination of the third one is smaller than the complement of the inclination of the other: it is (called) 'closed' (*maghlūqa*), with less than a right angle.[3]

If you want to construct this connected sundial at right angle, operate as you did above for the (first) declining sundial, but (you should know) that the length of its gnomon (goes) from the centre of the first (face) to the end of the sundial, namely, the end of the sundial which is pasted to the other declining sundial.[4] (The distance of) its centre (from the common intersection of the two faces) corresponds to the gnomon length of the sundial that was first made, on which there is an hour line, and which is called 'the declining sundial on its own' (*munḥarifa bi-infirādihā*). When it is connected to the other sundial, then it is called 'connected' *mawṣūla*.

Then complete the declination curves with the method (which makes use of) the azimuth and vertical shadow of the hours, as we have explained before. Join each declination curve with that of the same kind ((*maʿa jinsihi*) (on the first face). Determine the azimuth of the 'angle' (*samt al-zāwiya*) with respect to one of the faces (*rukhāma*)[5] at the solstices and connect each declination curve with the (marks at the) 'angle' of the faces. (Do this) likewise (for) the hour (lines). If one of these (marks) falls on one face and the other one on the other face, then connect them with the (corresponding mark on the) angle of the faces. When the (marks for the) hour (lines) and (for the) declination curves are completed, and you want (to know) the gnomon length, cleave (*ilzaq*) (one side of) the 'instrument with a right angle' (*al-zāwiya*) against the side of the wall, with its other side upon the centre of the circle (drawn on the ground for constructing the sundial markings on both faces). (The distance) from (the centre) to the side of the wall will be the gnomon length. Its position (on the sundial) will be given by the position of the plumb-line (which falls on the corner of the 'instrument with the right angle' at the base of the wall) at the 'horizon'.

The construction of the 'opened' and 'closed' *mawsūla*s will present no difficulty to anyone skilled in (the construction of) declining sundials.

{*Diagram*}

The (vertical) sundial declining by 40° to the meridian. It is connected to the other one. For latitude 36°.

<Text in the diagram:> The south-eastern face. Eastern line of the horizon. – Gnomon length for this declining sundial. – Cancer, Libra, <Capricorn>. – First, second, . . . , sixth (hour).

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[2] I.e., the angle formed by them is obtuse.

[3] I.e., the angle formed by them is acute.

[4] I.e., the length of the gnomon on the second face corresponds to the distance from the base of the gnomon on the first face to the common intersection of the two faces.

[5] I.e., the azimuth of the common intersection of the two faces, with respect to one of the sundials. This is necessary for drawing the marking at the common intersection of the sundials.

This (portion of) the page represents the ground for the sundial with declination 40°. – Line of the rising amplitude of Cancer. – Azimuth of the {first, second, third, fourth, fifth} (hour) of Cancer. – Azimuth of the first (hour) of Libra. – Azimuth of the {second, fourth, fifth} (hour) of Capricorn.

111 *On the construction of the inclined sundial (*al-māʾila*) by means of the construction of its (corresponding) declining sundial, on the side that is facing the sky.*

Determine the auxiliary shadow at the hour (you wish) for this declination (of the sundial), which is the one you have previously kept in Chapter 109 for the time when it is needed. Then find the altitude corresponding to this shadow (considered horizontal) from its (corresponding cotangent) table. Add the result to the inclination of the sundial plate (*mayl al-rukhāma*) if the azimuth of the hour and that of the sundial[1] are in two (opposite) directions, or take the difference between them if they are in one single direction. If the result[2] is greater than 90°, subtract it from 180° and take the horizontal shadow of the result: this will be the (auxiliary) shadow above its centre[3] for that hour on the inclined sundial. If the sum (or the difference) is smaller that 90°, then take likewise its horizontal shadow: this will be the (auxiliary) shadow underneath the centre. You should know that the distance of the 'centre' of the inclined sundial[4] from the 'horizon' is the tangent of the inclination of the sundial plate. *p. 202*

Once you have determined the (auxiliary) shadow of the hour, take a plane surface (*rukhāma*) and trace on it the 'horizon line', the vertical axis (*khaṭṭ watad al-arḍ*) as well as the length of a gnomon (*qadr qāmatin*), which you divide into twelve parts. Take this as a scale (*masṭara*) (for the construction). In terms of the parts of this scale open the compasses to the (auxiliary) shadow of the hour on the inclined sundial, and place one leg of the compass at the first centre[5] and the other one in the direction of the 'horizon', if the shadow is above the centre, or in the direction of the earth, if the shadow is underneath the centre. Make a mark with the other leg on the vertical axis. Trace there (i.e., on the marks) lines parallel to the line of the 'horizon'. When you have completed all these lines, they will represent the 'lines of (auxiliary) shadow' of the hours.

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[1] The 'azimuth' of the sundial is the 'uphill' direction on the inclined surface.

[2] I.e., the sum of the altitude and the inclination.

[3] I.e., the shadow occurs above the base of the gnomon.

[4] I.e., the base of the gnomon.

[5] The 'first centre' has not been defined yet, but it corresponds to the standard 'centre', i.e., the base of the perpendicular gnomon. One step in the construction is here omitted, namely, the determination of this 'first centre', whose distance from the horizon is the tangent of the inclination.

To find the 'distances' of the hours, consider the (auxiliary) shadow (on the vertical sundial): if it is above the centre, add it to the cotangent of the inclination, and if it is underneath, take the difference between them. Keep the result in mind as a first quantity (*uḥfuẓhu awwalan*). Place one leg of the compass at the intersection of the line of 'horizon' with the vertical axis at draw a semicircle, which you divide into 180 (equal parts). Starting from the 'horizon', take from these parts the inclination of the sundial plate, and trace a straight line[6] from (this graduation of the semicircle) to the 'second centre'.[7] Open the compass to the gnomon length on the inclined sundial and place one leg at the intersection of the 'horizon' with the vertical axis – which is the second centre – and make a mark with the other leg on the vertical axis. Trace there a line parallel to the 'horizon'; place one leg at the intersection of this line with the radial line and the other one upon the 'second centre'. Consider how many parts of the (construction) scale this opening corresponds to: this will be the Cosecant of the inclination of the sundial plate, which is the 'base' (*aṣl*) (used) for (constructing) all inclined sundials.[8] Open the compass to the first quantity kept in mind in terms of the gnomon length on the inclined sundial, divide this opening by the 'base', and make a second scale with (the result). Open the compass on this scale to the 'distance' of the hour on the (corresponding) declining sundial – this is known from Chapter 109 on the construction of the declining sundial. Place one leg at the intersection of the 'line of < (auxiliary) shadow >' of the hour with the vertical axis and make a mark with the other one on the 'line of (auxiliary) shadow' of the hour: this will be the location[9] of the hour (mark) on the inclined surface. Do this for Cancer and Capricorn and join (the marks of) the hour (lines) and (of) the declination curves in the same ways as you have joined them on the declining sundials. If there is no 'distance', then (the mark will be made) < on > the vertical axis. And if the 'distance' is infinite, then it is not possible (for the shadow) to fall on the declining surface. < ... > Then, in terms of these parts, open (the compass) to the horizontal shadow of the hour – i.e., the vertical projection (of the tip of the gnomon) – and < place > one leg at the vertical projection and the other one where it cuts the line parallel to the 'horizon': this will be the location of the hour on the inclined surface, God Almighty willing. Know this and you will get it right.

{*Diagram*}

[6] Literally "an infinite straight line", which does not make sense here since its extremities are defined.

[7] The 'second centre' – which is defined by Najm al-Dīn in the next sentence – is the intersection of the 'horizon' with the vertical axis; it coincides with the base of the horizontal gnomon.

[8] Cf. Chapter 115, where the 'base' (i.e., the Cosecant) is also used as an auxiliary quantity in the computation of the 'distance'.

[9] 'Declination' in the text.

Diagram of the (sundial) declining from the meridian by 50° and inclined eastwards by 50°, for latitude 36° north. This (sundial) works from midday to the end of daylight.

<Text in the diagram:> Line of the western horizon. – Centre of the (gnomon which is) perpendicular (to the sundial). – Centre of the (gnomon which is) horizontal (*munakkas*). – Length of the first gnomon on which the construction is based. – Length of the second gnomon (which is) horizontal, and does not move. – Parallel of Capricorn, parallel of the equinox, parallel of Cancer. – Sixth, seventh, . . . , twelfth (hour). – <*ʿAṣr*>. – Vertical projection (of the gnomon).

112 *On the construction of the inclined sundial (*māʾila*) by means of its (corresponding) declining sundial, the construction being on the side that is facing the earth.*

Take the (auxiliary) shadow of the hour (on the corresponding vertical sundial), which you have already kept in mind for this inclined sundial, as previously mentioned. Add it to the shadow of the inclination of the sundial. Divide the sum by the Cosecant of the inclination of the sundial. Multiply the quotient by the 'distance' of the hour of that declining sundial whose inclination you want. The product will give you the 'distance' for that hour on the inclined sundial.[1] Know this. If you don't want to consider (such) calculations (?) then determine it (with the method that) was mentioned before. Yet we want only concision in this chapter, and (we want) to make it easy for anyone who wishes to construct inclined sundials. It is necessary that the maximal 'distance' of the 'horizon' on the declining sundial be known, or the hour with the maximal distance (?). Determine its 'distance' on the inclined sundial and mark the 'distance' of the hour on the opposite (?? *mukhālifa*) declining sundial. This will be the horizon. Take twelve of these parts: this will be the gnomon length. Make it a scale. Our aim in this was only to .... the construction of the hours drawn (?) on the sundial. In terms of these parts open the compass to the distance of the 'horizon' which you have determined, and place one leg at the side of the sundial plate and the other one where it cuts the horizon line of the declining sundial: this will be the position of the centre of the perpendicular gnomon. Let a plumb-line fall (along the inclined surface): this will be the vertical axis. Open the compass to the complement of the inclination of the sundial plate and place one leg at the centre (just) mentioned and with the other one make a mark on the vertical axis: this will give you the position of the 'horizon' on that inclined sundial. Trace a line of indeterminate length.[2] pp. 201, 201

Determine the (auxiliary) shadow of the hour, as you did before. Example: if you subtract the inclination of the sundial plate – which is larger than the

[1] The above computation is erroneous.
[2] Literally "an infinite line". See n. 2 on p. 272.

altitude of the auxiliary shadow – (from it), then you can determine the hour (on that sundial). Take the horizontal shadow of the difference: this will be the auxiliary shadow on the inclined sundial. If the inclination of the sundial plate is larger than the altitude of the auxiliary shadow, you should know that at that time (the shadow) cannot fall on the side (facing) the earth, but it will fall on the side (facing) the sky. When you have determined the (auxiliary) shadow on the inclined sundial, open the compass to its quantity in terms of the shadow scale mentioned, place one leg at the centre of the perpendicular (gnomon), and make a mark with the other one underneath it on the vertical axis. Trace there a straight line of indeterminate length parallel to the 'horizon'. When the 'lines of (auxiliary) shadow' at the solstices have been completed, open the compass to the 'distance' of that hour, which is known in terms of the scale mentioned above. Place one leg at the (second) centre[3] and the other one where it cuts the 'horizon' line in the direction of the hour on the declining sundial. Let a plumb-line fall from there: the intersection of the thread of the plumb-line with the line of the (auxiliary) shadow of the hour will give you (the mark of) the hour on the inclined sundial. Join together the hour (marks) of Capricorn and Cancer. Then join (the marks of) both declination curves as you did before. For the declination line of Aries, determine the 'distance' of its 'horizon' and the shadow of the sixth hour (at the equinox), and trace a straight line from the 'horizon' to the line of the hour that is on the inclined sundial. Write the names of the signs on their declination curves, and likewise (number) the hour (lines).

You should know that I have designed (*istanbaṭtu*) a table (based on) this method from the (general) sundial tables (*jadāwil al-basīṭāt*) for (constructing) all inclined sundials, on the sides (facing) the sky and (on those facing) the earth, declining or (text: and) perpendicular to all diameters and directions. I do know that I have been preceded (by someone else) in completing the procedures of these methods (*ilā istikmāl sulūk hadhihi al-masālik*). God knows best in this matter.

Appendix: Know that when the altitude of the auxiliary shadow on the perpendicular surface equals the inclination of the sundial plate, then it is obscured on both sides. If the sun slightly rises, then its side (facing) the sky will be illuminated, and the side (facing) the earth will be obscured. (But) if the sun decreases slightly then its side (facing) the earth will be illuminated, and the side (facing) the sky will be obscured. God known best.

{*Diagram*}

Diagram of the sundial declining from the meridian by 50° and inclined towards the east by 10°.

[3] Cf. Ch. 111.

< Text in the diagram: > Side of the sundial which faces the earth. – It operates from the beginning of daylight until the end of the third (hour), then it becomes shady.

<113 *On the construction of the horizontal sundial with which 41 problems can be solved.*>

With this horizontal sundial, you can determine the solar longitude, the declination, the meridian altitude, the time elapsed (of daylight) in seasonal and equal hours, the hour-angle, the altitude at (the beginning of) the *ʿaṣr* and at its end, the altitude at the seasonal and equal hours, and their azimuth and direction, the number of equal hours (during daylight), the altitude in the prime vertical, the (time) between the *ẓuhr* and the *ʿaṣr*, between (the beginning of) the *ʿaṣr* and sunset, between the beginning and end of the *ʿaṣr*, between (the end of) the *ʿaṣr* and sunset, between the *ẓuhr* and the end of the *ʿaṣr*, the durations of the (seasonal) hours, the (solar) azimuth at the beginning of the *ʿaṣr* and the azimuth at its end, the azimuth (corresponding to) any altitude, the direction of the sun, the time-arc, the altitude of the sun in the *qibla*, the azimuth of the *qibla* and its direction, the time-arc (of the sun when it is in the azimuth) of the *qibla*, the hour-angle (of the sun when it is in the azimuth) the *qibla*. The sum of all these operations is 30 operations (associated with) this design (of a horizontal sundial) illustrated (on this page). When you make more (markings) one can find the half arc and the rising amplitude, and when you mark the midday ascension alone (?? *min ghayriha*), then (you can) determine with it the ascensions of the ascendant and descendant. And when the shadow circles are marked on it, (you can) determine the midday shadow and the shadow at the beginning and end of the *ʿaṣr*. The total sum of these is 41 operations.[1] God Almighty knows best. *p. 189*

{*Diagram*}[2]

[114 *On the construction of the equal hours on the declining sundial.*. . .]

[. . . . . .] Trace a circle on the even ground and determine the cardinal directions. Trace the meridian line and the east-west line. Find the azimuth of that hour (you want to mark) from the sundial table already mentioned. Place the ruler on the azimuth and at the centre, and make a mark at the intersection of the ruler with the base of the declining (wall); keep it. [. . . ?] Let a plumb-line fall upon that mark, and make (another) mark at the intersection of the thread with the 'horizon': this will be the position of the 'distance' of the hour. Know this. Then, determine the vertical shadow of that hour and place one leg of the compass at the centre of the circle and the other one upon the mark (you had) *p. 196*

[1] I rather count 39!

[2] See Plate 13.

kept. Divide this opening (of the compass) into twelve parts, and in terms of these parts open <the compass> to the <vertical> shadow of the hour. <Place one leg at the intersection of the plumb-line with the 'horizon'> and the other one where it cuts the thread of the plumb-line: this will be the position of that hour. Do this operation for both solstices and join the (resulting) hour (marks) and (those of) each declination curve. For the parallel of equinox, mark the intersection of the east-west line with the base of the declining sundial, and let a plumb-line fall upon (this mark). The intersection of the plumb-line with the 'horizon' line will give you the 'horizon' of Aries. Then divide the meridian line which is on the ground into twelve (parts) and open the compass to the vertical shadow of the sixth hour (in terms of these parts). Place one leg at the intersection of the meridian line (on the sundial) with the 'horizon' and the other one where it cuts the meridian line: this will be the position of the sixth hour of Aries. <Connect it> (through a straight line) to its 'horizon'. (This will represent the day-line of Aries). (Proceed) in the same way if you want to construct (the markings for) the time-arc at each 5° or each 10° or each 3° or otherwise.

{*Diagram*}

Diagram of the sundial declining from the meridian by 45° towards the east, for latitude 36° north. Its hours are equal: they correspond to the time-arc at each 15°.

<Text in the diagram:> This is the southern face. – Line of the horizon. – Meridian line. – Centre. – Gnomon length. – Parallel of Capricorn, (parallel of) Libra, parallel of Cancer. – *ʿAṣr*.

115 *On the construction of the equal hours on the inclined sundial, by means of the construction of the (corresponding) declining sundial.*[1]

p. 203 Determine the auxiliary shadow of the hour (you wish) for this declination. Then find the altitude corresponding to this shadow from the (sundial) table. Add this to the inclination of the sundial plate if the azimuth of the hour and of the sundial are in two (opposite) directions, and take the difference between them if they are in one single direction. If what remains after this is smaller than 90°, take its horizontal shadow: this will be the (auxiliary) shadow of that hour above the centre on the inclined sundial. If it is greater that 90°, subtract it from 180° and take the horizontal shadow of the difference: this will be the (auxiliary) shadow of that hour underneath the centre on the inclined sundial.

You should know that the distance of the 'centre' of the inclined sundial from the 'horizon' equals the tangent of the inclination of the sundial plate. Once you have determined the (auxiliary) shadow of that hour on the inclined sundial, take a plane surface (*rukhāma*) and trace on it the 'horizon line' as

[1] The first third of this chapter is nearly identical to Chapter 111.

you have drawn it on the declining sundials. Then determine the maximal 'distance' on the vertical surface of the (declining) sundial, and keep it. Determine the Cosecant of the inclination of the sundial plate, as you have done previously — this is the 'base'[2] (which is used) for all inclined sundials. Consider whether the (auxiliary) shadow of that hour is above the centre, (and in this case) add it to the shadow of the inclination of the sundial plate. If it is below the centre, take the difference between them. Divide the result by the 'base', which is the Cosecant of the inclination of the sundial plate. Multiply the quotient by the 'distance' of the hour on the vertical surface. The result will be the 'distance' of that hour on the inclined sundial. Do this operation for both solstices and for the equinox. If something (of the hour-line) remains at the connection of the hour (lines) (with the limit of the sundial markings), then do this for the beginning of Taurus and Gemini, or their opposite signs, in case you would prefer this. Trace the hour-lines. Connect (the marks of) the declination curves, and write on each hour (-line) its number or its (corresponding equatorial) degree. (Proceed) in the same way, if you want to construct on the inclined surface (the markings of) the time-arc at each 5° or otherwise.

It is necessary that the gnomon length of the inclined sundial be known before constructing it, in order to restrict the entire construction within the surface of the sundial plate (*rukhāma*). For this you have to find the maximal 'distance' on the vertical surface, in the southern (*yamīn*) direction which you have kept before. If the (auxiliary) shadow (corresponding to) this 'distance' is above the centre, add together the shadow of this 'distance' and that of the inclination of the sundial plate. If it is underneath it, then take the difference between them. Divide the result by the Cosecant of the inclination of the sundial plate. Multiply the result by the 'distance' of the hour on the vertical surface. The product will be the maximal 'distance' on the inclined surface. Take knowledge of it. Now consider the maximal 'distance' in the northern (*yasār*) direction. Operate with it in the same way. Add the two 'distances' and divide the width of the plate by the sum: what you obtain will give you the construction scale. Take twelve parts thereof, which will give the gnomon length. With (this) scale construct the 'distances' and (auxiliary) shadows. The whole construction will hence be restricted within the limits of the (width of the) sundial plate. In the same manner (you can do it with) its length. This will present no difficulty to anyone skilled in the construction (of sundials). Take knowledge (of that).

<Remark:> Be aware that in this chapter I did mention multiplications and divisions (but these are) only to facilitate (the task of) the maker. I have already mentioned its construction[3] before this without having to use any multiplication or any division.

[2] This refers to an auxiliary quantity to be used later.
[3] I.e., the construction of an inclined sundial.

{*Diagram*}[4]

Diagram of the sundial declining eastwards to the meridian by 45° and inclined by 30° eastwards. For latitude 36° north.

< Text in the diagram: > Side of the sundial that faces the sky. – Centre of the first gnomon (which is) horizontal. – Centre of the second gnomon (which is) perpendicular. – < Length > of the first, horizontal, gnomon. – Length of the second gnomon (which is) perpendicular. – Parallel of Capricorn, Aries/Libra, < parallel of Cancer >.

116 *On the construction of the declining sundial with which the altitude and the azimuth can be known at any time you wish, without having to concern yourself with its inclination, or with the gnomon length and its centre.*

p. 196 Trace a circle on an even ground and determine the cardinal directions. Trace the azimuth lines (on the basic circle) as you have done previously for each 10° or otherwise. Mark the positions of the azimuth at the base of the sundial plate or of the wall and let a plumb-line fall upon this mark: this will give you the azimuth line. Write on it its number and direction. Then divide (the line) between the centre of the circle on the ground and the mark of the azimuth into twelve parts,[1] and open (the compass) to the vertical shadow of the desired altitude number, be it at each 10° or each 5° or each 6° or otherwise, and place one leg of the compass at the intersection of the azimuth line with the horizon and make a mark with the other one on the azimuth line which is on the vertical surface of the sundial. Do this operation for all azimuths. Connect the altitude marks. If you want to draw the declination curves, it is necessary to include the shadow. And whoever wishes not to include it, will not draw the declination curves and will extend the azimuth lines down to the base of the sundial and the altitude curves to both sides of the sundial plate, at the right and at the left.

{*Diagram*}

The sundial declining eastwards from the meridian by 45°, with which the altitude and the azimuth and its direction can be known, for latitude 36° north, (as well as) the rising amplitude, the altitude in the prime vertical, the meridian altitude and the declination and its direction.

< Text in the diagram: > Southern face of the sundial. – Gnomon length. – Azimuth lines: north, south. – Southern azimuth, northern azimuth. – Altitude arcs. – Parallel of Capricorn, < parallel of Aries >, parallel of Cancer.

< Remark: > Be aware that the azimuth lines are in red and the altitude arcs in black; and that the direction of the azimuth is indicated.

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[4] See Plate 14.

[1] The Arabic text is confused here, but the intended meaning is clear.

{Chapters 117 and 118 are missing.}

119 *On the construction of the seasonal hours, the altitude arcs (*al-muqanṭarāt*) and the azimuth (lines) on the inclined sundials, on the side of the sundial plate that faces the earth.*

The procedure (for constructing) the hour (lines) has already been mentioned. p. 203 For the azimuth, mark its 'distance' on the vertical surface corresponding to this sundial and keep it. Then add together the cotangent of the inclination of the plate and its tangent. Divide the sum by the Cosecant of the inclination. Open (the compass) to the value of the result in terms of the parts of the gnomon of the inclined sundial, and place one leg of the compass at the intersection of the 'horizon' with the vertical axis and the other one where it cuts the 'horizon'. Make a mark and keep it. Then divide the width of the sundial plate into 60 (parts) and in terms of these parts open the compass to the sine of the inclination of the sundial plate. Divide this opening into twelve parts and open (the compass) to the 'distance' of that azimuth on the declining sundial in terms of these. Place (one leg) at the intersection of the base of the inclined sundial with the vertical axis and make a mark on the base of the sundial. Trace a line (from) there to the mark you have kept: this will be the desired azimuth line. Do this operation up to the azimuth (of a shadow) that can still possibly fall on the sundial. Write their numbers and directions.

For the altitude arcs (*al-muqanṭarāt*), take the auxiliary shadow on the vertical surface (corresponding to) the sundial, with that altitude as argument. Determine the altitude corresponding to this shadow, and subtract from it the inclination of the sundial plate. Take the horizontal shadow of the difference: this will be the (auxiliary) shadow of this altitude arc on that inclined sundial. Open the compass to it with respect to the gnomon length of the inclined sundial, and place one leg at its centre and the other one where it cuts (the line) underneath the centre, that is the vertical axis. Trace there a line parallel to the horizon.

Then determine the 'distance' corresponding to this shadow. Its explanation is (as follows): Find the azimuth corresponding to the argument of that altitude arc for that (solar) longitude. Then determine the 'distance' for this azimuth on the vertical surface (corresponding to) this sundial and keep it. Add together the (horizontal) shadow of that altitude for that inclined sundial and the shadow of the inclination of the sundial plate. Divide the sum by the Cosecant of the inclination of the sundial plate. Multiply the result by the 'distance' you have kept. This will give you the 'distance' for that altitude arc. Open (the compass) to it in terms of the gnomon length of the inclined sundial, and place one leg at the centre and the other one on the 'line of the centre' (i.e., the line passing through the mark of the auxiliary shadow) parallel to the 'horizon'. Make a mark (there) and let a plumb-line fall from this mark onto

the shadow of the altitude arc that you have determined: the intersection of the plumb-line with the line of the shadow of the altitude arc will be the location of (the marking for) the altitude arc. Do this operation for all azimuth lines and for all altitude arcs. If you want (you can) trace the latter by means of (piecewise) linear segments or (you can draw them) pointwise (as smooth curves): these will be the altitude arcs. Number them between the arcs and (number also) the azimuth lines. (The construction) is now completed. Know it and you will get it right.

{*Diagram*}

Diagram of the sundial declining westwards from the meridian by 10°, for latitude 36° north. (Its) operation is on the side (facing) the earth, inclined by 10° towards the east.

<Text in the diagram:> Gnomon length. – Azimuth: north, south. – <Altitude arcs>. – Parallel of Cancer, <parallel of Aries>, parallel of Capricorn. – First, second, . . . , fourth (seasonal hour).

<Remark:> The (seasonal) hour, its (corresponding) altitude, and its azimuth and direction thereof can be determined with it, as well as the rising amplitude and the altitude in the prime vertical.

120 *On the construction of the inclined sundials whose inclinations are not in the direction of their declinations (and which are) on the side facing the sky.*

p. 203 This is the best known of all inclined sundials and the most remarkable one. I have never seen anyone who has mentioned the method of (constructing) them, and I have never seen their figure (anywhere). The way to construct them without calculation (is as follows): Consider the (sundial) table mentioned before and construct it (i.e., the sundial) with it (i.e., the table) as you have done other (sundials) before, without calculation and without (having to determine its) declination. (But) if you want to construct it through calculation, then determine the declination of this inclined sundial and find out the 'distances' of the hours and their (auxiliary) shadows for that declination. Add it to the inclination of the sundial plate. If the sum is smaller than 90°, take its horizontal shadow: this will be the (auxiliary) shadow of that hour underneath the centre. (But) if the sum is greater than 90°, subtract it from 180°; take the (horizontal) shadow of the difference: this will be the (auxiliary) shadow of that hour above the centre. This is (only) if the azimuth of the hour and that of the (corresponding) declining sundial are in a single direction; (but) if they are in two (opposite) directions, then subtract the altitude of the auxiliary shadow from the inclination of the sundial plate, and take the horizontal shadow of the difference: this will be the (auxiliary) shadow of

that hour underneath the centre. Trace there an imaginary line parallel to the 'horizon'. Then consider whether the (auxiliary) shadow is above the centre, (in which case) add it to the inclination of the sundial plate. If it is underneath the centre, take the difference between them. Divide (the sum or difference) by the Cosecant of <the inclination> of the inclined sundial, and multiply the result by the 'distance' of the hour on that (corresponding) declining sundial. The product will be the 'distance' on the inclined sundial. As for the azimuths, (their) construction has been mentioned before. We only wanted to add them.

Explanation: you should know that the width of the sundial plate is (counted) from the centre of the perpendicular (gnomon) to the base of the sundial plate. You should (also) know that the distance of the centre from the 'horizon' is always the tangent of the inclination of the sundial plate. The centre is always underneath the 'horizon' on the side (facing) the sky.

{*Diagram*}

Diagram of the sundial declining eastwards from the meridian by 45° and inclined by 60° towards the west. For latitude 36° north.

<Text in the diagram:> Side of the sundial plate that faces the sky. – Centre. – Gnomon length. – The distance of the centre from the 'horizon' is 20;47.[1] – Azimuth: north, south. – Parallel of Cancer, Aries/Libra, parallel of Capricorn. – First, second, ..., sixth (hour)/meridian line.

<Remark:> The seasonal hours are the lines in black; the azimuths are the lines in red. — The (seasonal) hour, its (corresponding) azimuth and direction thereof, and the rising amplitude can be determined with it, for latitude 36° north.

121 *On the construction of the inclined sundials made in the opposite direction than that of their declination, on the side facing the earth.*

Determine the 'distance' of the hour and the auxiliary shadow for the declining sundial (corresponding to) the sundial you want to construct. Then find the altitude of the auxiliary shadow and subtract it from the inclination of the sundial plate. Take the horizontal shadow of the difference: this will be the (auxiliary) shadow of that hour on the inclined sundial. Open the compass to its quantity and place one leg at the centre and the other one on the vertical axis. (Make a mark and) trace there an imaginary line parallel to the 'horizon': this will be the (auxiliary) shadow of the hour. Then add the (auxiliary) shadow of the hour to the cotangent of the inclination of the sundial plate, and divide the result by the Cosecant of the inclination of the sundial plate. Multiply the quotient by the 'distance' of the hour on the vertical surface (corresponding to) the sundial, that is the declining sundial without inclination (*qabl* *p. 203*

[1] This corresponds indeed to $12\tan(i = 60°)$.

maylihā). The result will be the 'distance' of the hour on the inclined sundial. Open the compass to its quantity and place one leg at the centre and the other one where it cuts the 'line of the centre'[1] parallel to the 'horizon'. (Make a mark there) and let a plumb-line fall (from this mark): the intersection of the plumb-line with the line of (auxiliary) shadow of the hour arc will be the location of the hour. Do this operation for (all) declination curves that can be represented on the sundial plate and always join the hour and declination (marks) together. The construction is completed.

You should know that the (auxiliary) shadow of the hours on the sides (facing) the earth are always underneath the centre, and on the sides (facing) the sky, (they are) always above the centre. You should (also) know that the most excellent constructions (involving) shadows are the inclined sundials, that the most noble inclined sundials are (those on the) side (facing) the earth, and that the nicest of them are (those whose inclinations are) in the opposite direction than their declination. The construction of the horizontal sundial and of the declining (vertical) sundial are for beginner, whereas that of inclined sundials are for the expert. But the construction of the inclined sundial is better than that of the horizontal or declining sundials, because the inclined sundial operates from sunrise until sunset on both sides (of the plate), whereas the horizontal sundial does not operate from sunrise until sunset, except if there is ...[2] a gnomon (*radāda*). Likewise for the declining (vertical) sundial: if the sun (shines) on this wall or plate, and the shadow of the gnomon is outside of the (range of the) horary markings, then the best (possibility for this) declining sundial would be that it operates from the beginning of the illumination of its face until when it becomes shady. Then if (at the same time) the other face becomes illuminated, then this is the best (possible) declining sundial. Anyone who does not one to rely on his senses (for constructing sundials) should consider what we have mentioned before. (Finally you should know that) the centre is always above the 'horizon' on the side (facing) the earth, (its distance from it) being the tangent of the inclination of the sundial plate. You should indicate with a red dot the centre of the gnomon.

{*Diagram*}

Diagram of the sundial declining eastwards from the meridian by 45° and inclined towards the west by 60°. For latitude 36° north.

<Text in the diagram:> The side of the sundial plate that faces the earth. – Gnomon length. – Parallel of Capricorn, parallel of Aries and Libra, parallel of Cancer. – Line of the eleventh (hour): 11. – Line of the western horizon, which is the line of the twelfth (hour): 12. – Setting point of Aries and Libra. – Setting point of Cancer.

[1] Cf. Chapter 119.
[2] The text has a blank space here.

< Remark: > Eleven hour (lines) cannot be represented on it at summer solstice, (since) they occur on the side facing the sky, which is the figure that precedes it,[3] (on) which (the hour-lines are drawn) up to the sixth (hour). It is not possible to extend the shadows of the hours (indefinitely) on a page: this would only be possible on a very large sundial plate. Yet (even) the eleventh (hour-line) is extensive, and this is its representation.

[122 *On the construction of the vertical sundial for latitude 36° parallel to the east-west line, on the northern face*.]

... ... *p. 193*

[Given the state of the text and the impossibility of a meaningful reconstruction, no translation is included here. See, however, the commentary.]

{*Diagram*}

Diagram of the hour-lines of (the vertical sundial parallel to) the east-west line, on the northern face. For latitude 36°.

[3] Cf. Chapter 120.

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Part IV

APPENDICES

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APPENDIX A

TABLE OF 'DECLINATIONS AND EQUATIONS'

On **D**:24v appears a table of 'equations of stars', which is in fact the function $5 \tan \Delta$.[1] This auxiliary quantity is used in computations of the half-excess of visibility of stars. The sine of the half-excess will be given by multiplying this 'equation' (called "sine of the excess" – *jayb al-faḍl* – by al-Marrākushī[2]) by the horizontal shadow (to base 12) of the complement of the latitude. This table, which is very poorly computed, is also quite superfluous, since Najm al-Dīn's corpus already includes a table of $d(\Delta)$. I have not been able to figure out how it could have been compiled, but it is not dependent upon his own shadow table.

Δ	$5\tan\Delta$	Δ	$5\tan\Delta$	Δ	$5\tan\Delta$
1	0;05,14,15	31	3;00,15,11	61	9;01,30,03
2	0;10,28,18	32	3;07,27,31	62	9;23,17,10
3	0;15,42,22	33	3;14,49,10	63	9;48,21,02
4	0;20,16,00	34	3;22,30,17	64	10;15,13,04
5	0;26,09,22	35	3;30,28,07	65	10;44,34,06
6	0;31,22,10	36	3;37,17,46	66	11;15,14,15
7	0;36,34,30	37	3;46,04,02	67	11;48,19,10
8	0;41,46,01	38	3;53,56,35	68	12;23,20,08
9	0;46,56,47	39	4;02,15,45	69	13;01,11,29
10	0;52,06,55	40	4;12,05,02	70	13;43,02,47
11	0;58,44,34	41	4;21,16,18	71	14;30,03,19
12	1;03,59,13	42	4;30,26,58	72	15;24,02,40
13	1;11,15,25	43	4;39,38,58	73	16;22,17,30
14	1;14,50,11	44	4;49,49,19	74	17;27,09,07
15	1;20,24,47	45	5;00,00,00	75	18;40,05,02
16	1;26,01,24	46	5;10,10,03	76	20;04,12,01
17	1;31,03,10	47	5;20,29,05	77	21;40,21,09
18	1;36,00,11	48	5;31,31,04	78	23;32,40,06
19	1;42,01,14	49	5;43,25,08	79	25;44,39,40
20	1;48,14,21	50	5;56,19,45	80	28;21,20,02
21	1;54,19,54	51	6;10,24,04	81	31;34,18,01
22	2;00,36,22	52	6;24,03,09	82	35;35,03,06
23	2;07,15,21	53	6;38,42,17	83	40;43,20,10
24	2;13,36,45	54	6;53,25,05	84	47;34,11,08
25	2;19,13,31	55	7;08,27,00	85	57;08,40,02
26	2;26,19,19	56	7;24,44,18	86	71;34,13,04
27	2;32,12,08	57	7;41,31,38	87	96;01,17,20
28	2;39,31,10	58	8;00,02,03	88	141;27,21,40
29	2;46,13,06	59	8;19,40,19	89	285;03,19,24
30	2;53,17,52	60	8;39,34,10	90	—

1 On this auxiliary functions and related tables see King, *SATMI*, I, § 7.

2 al-Marrākushī, *Jāmiʿ*, I, pp. 89–91 [*fann* 1, *faṣl* 29]; Sédillot, *Traité*, pp. 207–211.

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APPENDIX B

NAJM AL-DĪN'S PROPORTION TABLES

The contents of Najm al-Dīn's "table of proportions" reproduced on pp. 7–8 of the edition is here rendered with modern mathematical notation.

Analysis: Rows 1, 4, 5, 7, 10, 11, 12 are identical or equivalent to rows in al-Marrākushī's table. The statement in the header attributing the first half to al-Marrākushī is thus only partially correct. The marginal note saying that the first half is not due to al-Marrākushī but rather to "the Ancients" (referring to earlier Muslim authors) is also only partially correct! The formulæ implied are of course older than al-Marrākushī, but their representation in a four-entry tabular format was new in the thirteenth century.

New notation introduced in the table: α'' and λ'' denote the distance from the nearest solstice along the equator and ecliptic, respectively. dirSin is the auxiliary function "directed sine" (*jayb al-tartīb*). $\mathrm{eq}\,a$ is the auxiliary function "equation of the azimuth" (*taʿdīl al-samt*). $\mathrm{arg}\,a$ is the auxiliary function "argument of the azimuth" (*ḥiṣṣat al-samt*). λ_z is the point of the ecliptic which culminates at the zenith: $\delta(\lambda_z) = \phi$. λ_{ZM} is the point of the ecliptic which, in Mecca, culminates at the zenith; clearly we have $\delta(\lambda_{\mathrm{ZM}}) = \phi_M$. h_x is the "altitude when the azimuth begins to increase and stops to diminish with respect to the degrees north of the zenith" (the astronomical meaning is unclear!).[1] λ_J is the longitude of the "midheaven of the ascendant", i.e., the point of the ecliptic midway between the ascendant and the descendant. λ_M is the longitude of "upper mid-heaven", i.e., the point of the ecliptic intersecting the meridian. h_Q and a_Q are the altitude and azimuth of the ecliptic pole. h_J is the altitude of the "midheaven of the ascendant". h_{10} is the altitude of the nonagesimal λ_{10}, the point of the ecliptic delimiting the ninth and tenth astrological houses; when the ascendant is on the horizon $\lambda_{10} = \lambda_M$. δ_2 and Δ_2 denote the second declination.

[1] The same quantity with the same definition also occurs in Najm al-Dīn's shorter treatise on spherical astronomy (MS Ambrosiana 227a, Chapter 27.)

TABLE B.1. Najm al-Dīn's 'Table of Proportions'

1	$\operatorname{Sin}\lambda'$	$\operatorname{Sin}\delta(\lambda)$	R	$\operatorname{Sin}\varepsilon$
2	$\lvert\phi-\delta\rvert$	$\overline{h_m}$	1	1
3	$\lvert\overline{h}_m-\delta\rvert$	ϕ	1	1
4	$\operatorname{Cos}h_m(\lambda)$	midday shadow	$\operatorname{Sin}h_m$	g
5	$\operatorname{Sec}[h]$	g	R	$\operatorname{Sin}h$
6	$\operatorname{Cot}(\overline{\delta}$ or $\overline{\Delta})$	$\operatorname{Sin}d$	$\operatorname{Cot}\phi$	R
7	$\operatorname{Cos}\delta$	$\operatorname{Sin}\lambda''$	R	$\operatorname{Cos}\alpha'$
8	$\operatorname{Cos}\beta$	$\operatorname{Sin}\alpha''$	$\operatorname{Cos}\Delta$	$\operatorname{Sin}\lambda''$
9	$\frac{1}{2}(\operatorname{Sin}h_m(\lambda)+\operatorname{Sin}h_m(\lambda^*))$	$\operatorname{Sin}B$	1	1
10	$\operatorname{Sin}B$	$\operatorname{Sin}h_m-\operatorname{Sin}h$	R	$\operatorname{Vers}t$
11	$\operatorname{Sin}B$	$\operatorname{Sin}h$	R	dirSin
12	$\operatorname{Sin}a$	$\operatorname{eq}a=\arg a\pm\operatorname{Sin}\psi$	R	$\operatorname{Cos}h$
13	$\operatorname{Sin}\phi$	$\operatorname{Cos}\phi$	$\arg a$	$\operatorname{Sin}h$
14	$\operatorname{Sin}B(\lambda_{\mathrm{ZM}})$	$\lvert\operatorname{Sin}h-\operatorname{Sin}h_m(\lambda_{\mathrm{ZM}})\rvert$	R	$\operatorname{Vers}\Delta L$ $[\Delta L<D(\phi,\lambda_{\mathrm{ZM}})]$
15	$\operatorname{Sin}B(\lambda_{\mathrm{ZM}})$	$\lvert\operatorname{Sin}h-\operatorname{Sin}h_m(\lambda_{\mathrm{ZM}})\rvert$	R	$\operatorname{Vers}\Delta L$ $(D>\Delta L)$
16	$[\operatorname{Sin}]h_0$	$\operatorname{Sin}(\delta$ or $\Delta)$	R	$\operatorname{Sin}\phi$
17	$\operatorname{Sin}\phi$	$\operatorname{Sin}h_x$	$\operatorname{Sin}\delta$	R
18	$\operatorname{Cos}h$	$\operatorname{Cos}(\delta$ or $\Delta)$	$\operatorname{Sin}t$	$\operatorname{Cos}a$
19	$\operatorname{Sin}\psi$	$\operatorname{Sin}(\delta$ or $\Delta)$	R	$\operatorname{Cos}\phi$
20	$\operatorname{Sin}\psi$	$\operatorname{Sin}d$	$\operatorname{Cos}(\delta$ or $\Delta)$	$\operatorname{Sin}\psi$
21	$\delta=\phi$	$\delta(\lambda_z)$	1	1
22	$\operatorname{Sec}h_m$	$\operatorname{Vers}D-\operatorname{Vers}t$	$\operatorname{Sec}h/60$	60
23	$\operatorname{Cos}h_J$	$\operatorname{Sin}\lvert\lambda_J-\lambda_M\rvert$	R	$\operatorname{Cos}a_Q$
24	$\operatorname{Sin}\lvert\lambda_J-\lambda_H\rvert$	$\operatorname{Sin}h_{10}=\operatorname{Sin}h_m(\lambda_M)$	R	$\operatorname{Sin}h_J(=\operatorname{Cos}h_Q)$
25	$\operatorname{Sin}(\delta$ or $\Delta)$	$\operatorname{Sin}h_d$	R	$\operatorname{Sin}\phi$
26	$\operatorname{Sin}B$	$\lvert\operatorname{Sin}h_d-\operatorname{Sin}h_m\rvert$	R	$\operatorname{Vers}90^\circ$
27	$\operatorname{Sin}\tilde{\beta}$?	$\operatorname{Cos}\Delta_2(\lambda)$	$\operatorname{Sin}\Delta$	$\operatorname{Cos}\varepsilon$
28	$\operatorname{Cos}\phi/R$	$\operatorname{Sin}B$	R	$\operatorname{Cos}(\delta$ or $\Delta)/R$
29	$\operatorname{Sin}\operatorname{eq}(\lambda')$	$\operatorname{Tan}\delta_2$	R	$\operatorname{Tan}\varepsilon$
30	$\operatorname{Sin}\phi$	$\operatorname{Sin}\psi$	$\operatorname{Cos}\phi$	$\operatorname{Sin}h_0$

APPENDIX C

NAJM AL-DĪN'S STAR TABLE AND THE STARS FEATURED ON ILLUSTRATIONS OF RETES

C.1 *The star table*

We present here an edition of Najm al-Dīn's star table, which gives the equatorial coordinates of 349 stars.[1] The table is contained among the set of tables accompanying Najm al-Dīn's auxiliary tables that have been discussed in the introduction.[2] A recomputation of the ecliptic coordinates from the equatorial ones, assuming Najm al-Dīn's parameter of the obliquity 23;35°, is also provided. The reader will verify for himself that the resulting ecliptic coordinates do not agree very well with those depending upon Ptolemy's star catalogue. In the last column, a tentative identification of the stars is given; the number in brackets is the cumulative number of Ptolemy's star catalogue in his *Almagest*.[3] Question marks indicate uncertain identifications. An exclamation mark denotes an obvious disagreement between the name of a star and its coordinates.

In a post-scriptum to the table, which is reproduced after the table with translation, Najm al-Dīn informs us that he has not compiled this table himself, but simply copied it from sources he does not identify; he also says that he could not determine the epoch of the table. The motivation of the person who compiled it was probably to include roughly one star for each degree of right ascension. Najm al-Dīn's statement about precessional adjustment is stunning: he erroneously suggests – blindly quoting his source – to add one degree every seventy years to the *right ascension*, whereas, of course, it is the longitude which is linearly dependent on precession. I have not conducted a detailed numerical analysis of this table. Inspection of a few important stars suggests a date around the mid-thirteenth century. Obviously, further investigation of this table would be worthwhile. The reason for including it in this study, however, is that the labels and positions of the star-pointers featured

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[1] There are 350 entries but one star occurs twice, as nos. 1 and 350.

[2] **B**:148v–151r. The table is labelled *Jadwal maṭāliʿ al-kawākib wa-abʿādihā wa-jihatihi*. Each page bears three columns, each with four subcolumns giving the name (*asmāʾ*), right ascension (*maṭāliʿ*), declination (*buʿd*) as well as the sign (*jiha*) of the declination (north or south).

[3] The correspondence between Ptolemy's stars and modern identifications is based on Kunitzsch 1986-91, pp. 187–194 and Toomer 1998. Several of these are uncertain.

on the illustrations of astrolabe retes in Najm al-Dīn's treatise depend directly upon it. This will be treated in details in the next Section of this Appendix. An asterisk next to the number of a star in the following table indicates that the star is featured on at least one of the illustrations of the instrument treatise.

TABLE C.1. Najm al-Dīn's Star Table, with recomputation of the ecliptic coordinates from the equatorial ones

No	Name	α'	Δ	λ	β	Identification
1	*awwal al-naʿāʾim al-ṣādira*	0;0	-27;25	270;00	-03;50	ϕ Sgr (576)
2	*mankib al-rāmī*	2;33	-26;42	272;17	-03;08	σ Sgr (575)
3	*raʾs al-rāmī*	3;26	-21;22	273;12	02;11	ξ^2 Sgr (578)
4*	*al-nasr al-wāqiʿ*	4;0	38;15	276;39	61;44	α Lyr (149)
5	*ṭaraf dhanab al-ḥayya*	5;0	3;33	275;36	27;02	θ Ser (280)
6	*katif al-rāmī*	6;0	-28;0	275;19	-04;32	σ Sgr (575) ?
7	*nayyir al-qilāda*	7;12	-21;27	276;42	01;58	π Sgr (580) ?
8	*rukbat al-rāmī*	8;20	-41;30	276;33	-18;06	α Sgr (593)
9*	*dhanab al-ṭāʾir*	9;0	12;6	280;48	35;21	ζ Aql (294)
10	*ākhar al-qilāda*	10;27	-19;20	279;53	03;53	υ Sgr (583) ?
11*	*al-ʿuqāb*	11;36	18;4	284;41	41;03	?
12	*al-māʾil ʿan mankib al-ʿuqāb*	12;19	2;6	283;37	25;06	δ Aql (297)
13	*janūbī al-ẓalīmayn*	13;0	-2;3	283;55	20;54	ι Aql (298) ?
14	*al-ẓalīm al-thānī*	14;10	2;39	285;43	25;28	λ Aql (300) ?
15	*mirfaq al-rāmī al-aysar*	15;0	-35;2	282;31	-12;06	51+52 Sgr (588)
16*	*minqār al-dajāja*	16;0	26;34	292;02	48;56	β^1 Cyg (159)
17	*raʾs al-dajāja*	17;38	27;20	294;26	49;25	ϕ Cyg (160)
18	*mankib al-ʿuqāb [al-aysar]*	18;26	9;25	291;29	31;38	ϕ Aql (291 (290) ?)
19*	*al-nasr al-ṭāʾir*	19;33	7;13	292;22	29;17	α Aql (288)
20	*ʿunuq al-ʿuqāb*	20;42	5;24	293;20	27;19	β Aql (287)
21*	*mirfaq al-dajāja [al-ayman]*	21;0	43;20	306;51	64;14	δ Cyg (164)
22	*raʾs al-sahm*	22;0	17;54	297;28	39;24	γ Sge (281)
23	*tālī raʾs al-ʿuqāb*	23;0	2;30	295;19	24;04	θ Aql (296) ?
24	*shamālī [saʿd] al-dhābiḥ*	24;9	-14;30	293;32	07;07	65 Psc (701)
25*	*janūbī al-dhābiḥ*	25;6	[-]14;2	294;31	07;26	ψ^2 Psc (703)
26	*muqaddam sākib al-māʾ*	26;10	-50;0	288;45	-28;07	?
27	*ḍilʿ al-tinnīn al-thānī*	27;55	63;45	00;11	78;03	ρ Dra (56) ?
28	*rijl al-dajāja*	28;30	48;56	324;02	67;13	o^1 Cyg (173) ?
29	*tālī rijl al-dajāja*	29;0	44;20	319;44	62;58	o^2 Cyg (174) ?
30*	*ṣadr al-dajāja*	30;15	37;55	316;23	56;42	γ Cyg (162)
31*	*dhanab al-dulfīn*	31;13	9;0	305;44	28;46	ε Del (301)
32	*wasaṭ al-qaʿūd* [MS: *ʿuqūd*]	32;17	13;50	308;18	33;12	α Del (305 (306) ?)

No	Name	α'	Δ	λ	β	Identification
33	*rukbat al-jady al-yusrā*	33;20	-29;32	298;58	-09;16	ω Cap (611)
34	*saʿd bulaʿ*	33;25	11;40	308;54	30;49	ν, μ or ε Aqr (634, 635 or 636) !
35	*shamāl al-qaʿūd* [MS: *ʿuqūd*]	34;13	13;45	310;26	32;38	γ Del (307) ?
36*	*rukbat al-dajājat al-yusrā*	35;19	31;34	319;02	49;17	ξ Cyg (172)
37*	*al-ridf wa-huwa dhanab al-dajāja*	36;5	42;57	327;59	59;27	α Cyg (163)
38	*ẓahr al-jady*	37;0	-20;23	304;21	-01;08	θ or ι Cap (619 or 620)
39	*rijl al-dajājat al-yusrā*	38;6	38;50	327;06	55;05	ν Cyg (171)
40	*janūbī qiṭʿ al-qaws*	39;40	12;0	315;49	29;27	ε Sgr (572)
41	*rukbat al-dajājat al-yumnā*	40;11	41;0	331;22	56;18	ω Cyg (175)
42	*janāḥ al-dajāja*	41;14	26;50	323;33	43;01	ζ Cyg (170) ?
43	*shamāl qiṭʿ al-faras*	42;19	17;0	320;29	33;26	γ or δ Equ (313 or 314)
44	*saʿd al-suʿūd*	43;54	-8;34	313;54	08;33	β or ξ Aqr or 46 Cap (632, 633 or 628)
45	*janūbī baṭn al-jady*	44;0	-17;0	311;38	00;25	ζ Cap (614)
46	*saʿd nāshira*	45;15	-20;0	311;55	-02;48	γ Cap (623)
47	*dhanab al-jady*	46;57	-19;45	313;32	-03;01	δ Cap (624)
48*	*fam al-faras*	47;58	-6;13	318;30	09;37	ε Peg (331)
49	*kitf al-faras*	48;30	30;56	333;52	44;18	β Peg (317) ?
50	*muqaddam al-ḥūt*	50;0	-41;0	309;16	-24;02	?
51	*tālī muqaddam al-ḥūt*	51;6	-50;0	306;29	-32;43	?
52	*saʿd al-mulk*	52;11	-4;20	323;08	10;06	α or o Aqr (630 or 631)
53	*saʿd al-buhām*	53;54	2;25	327;05	15;55	θ or ν Peg (329 or 330)
54	*rukbat al-faras*	54;15	21;52	335;12	33;56	ι Peg (333)
55	*kaʿb* [MS: *kaff*] *al-faras*	55;25	30;56	341;11	41;45	π^2 Peg (332)
56*	*awwal al-khibāʾ*	56;11	-5;30	326;34	07;41	γ Aqr (637) ?
57*	*qalansuwat al-multahib*	57;30	54;30	04;38	60;34	ε Cep (83)
58*	*wasaṭ al-khibāʾ*	58;11	-3;7	329;17	09;15	ζ Aqr (639) ?
59	*janūbī fam al-ḥūt*	59;0	-50;0	312;06	-34;43	?
60*	*ākhar al-khibāʾ*	60;8	-3;50	330;52	07;54	η Aqr (640) ?
61	*khārij al-multahib*	61;14	55;55	09;44	60;06	δ Cep (87)
62	*saʿd al-humām*	62;0	7;34	336;52	17;52	ζ Peg (325)
63	*saʿd maṭar*	63;19	26;13	346;30	34;29	η Peg (322)
64	*awwal saʿd bāriʿ*	64;2	19;50	344;03	28;24	λ or μ Peg (323 or 324)

No	Name	α'	Δ	λ	β	Identification
65	*thānī saʿd bāriʿ*	65;3	20;13	345;13	28;22	λ or μ Peg (323 or 324)
66*	*fam al-ḥūt al-janūbī*	66;0	-34;10	324;48	-22;20	α PsA (670)
67	*fam al-samaka*	67;0	0;0	338;45	09;00	β Psc (674)
68*	*matan al-faras*	68;0	11;27	344;12	19;12	α Peg (318)
69*	*mankib al-faras*	69;0	23;30	350;36	29;48	β Peg (317)
70	*shamālī fam al-ḥūt*	70;0	0;40	341;18	07;15	7 Psc (676) ?
71	*raʾs al-samaka*	71;6	0;40	342;19	06;50	γ Psc (675) ?
72*	*shamālī al-karab*	72;11	11;30	348;12	17;37	τ Peg (319)
73	*ẓahr al-samaka*	73;11	2;37	345;32	09;04	θ Psc (677)
74	*janūbī al-karab*	74;0	9;52	349;13	15;24	υ Peg (320)
75	*mutaqaddam ẓahr al-samaka*	74;30	-3;38	344;20	02;47	λ Psc (680) ?
76	*tālī ẓahr al-samaka*	75;28	1;40	347;17	07;18	ι Psc (678) ?
77	*tālī baṭn al-samaka*	76;18	2;23	348;21	07;38	51 Psc (683) ?
78	*shamālī kaff al-musalsala*	77;16	42;37	09;40	43;16	λ And (343)
79*	*wasaṭ kaff al-musalsala*	78;0	39;50	08;20	40;37	κ And (342)
80	*rāʿī al-jady*	79;50	23;23	00;39	25;23	?
81	*dhanab al-samaka*	80;52	2;30	352;37	05;56	ω Psc (681)
82	*awwal khārij al-māʾ*	81;58	-20;54	344;10	-15;57	2 Cet (671)
83	*shamālī khārij al-māʾ*	82;19	-18;40	345;25	-14;03	6 Cet (672)
84*	*ṣurrat* (!) *al-faras wa-huwa shamālī al-muʾakhkhar*	83;54	24;15	04;46	24;32	α And (315)
85*	*janāḥ wa-huwa janūbī al-muʾakhkhar*	85;19	10;26	359;56	11;26	γ Peg (316)
86*	*dhanab qayṭus*	86;11	-12;46	351;21	-10;10	72 Ori (742)
87	*munīr al-zawraq*	87;53	-46;30	335;30	-40;53	α Phe (not in Ptolemy)
88	*janūbī khārij al-māʾ*	88;0	-22;30	348;49	-19;45	7 Cet (673)
89	*qāʾima dhāt al-kursī*	90;11	58;40	33;26	51;27	κ Cas (188)
90*	*raʾs dhāt al-kursī*	91;18	49;0	25;42	43;18	ζ Cas (178)
91*	*dhanab al-ḥūt*	92;9	-22;0	352;45	-20;56	β Cet (733)
92	*al-judayy*	93;11	84;15	76;04	65;27	α UMi (1)
93	*shamālī baṭn al-ḥūt*	94;12	34;25	18;53	29;36	μ or ν And (347 or 348) ?
94	*janūbī al-ḍifdiʿ*	95;15	-35;0	348;51	-33;45	?
95	*wasaṭ thalāthat al-samaka*	96;0	4;0	07;06	01;16	ε Psc (685)
96*	*nayyir baṭn al-ḥūt*	97;58	31;55	20;48	25;57	β And (346)
97	*muqaddam al-naʿamāt*	99;2	-14;20	02;25	-16;43	η Cet (727)
98	*tālī thalāthat al-samaka*	100;4	3;7	10;28	-01;09	ζ Psc (686)

No	Name	α'	Δ	λ	β	Identification
99	*rukbat al-khaḍīb*	101;10	55;0	37;21	44;56	γ Cas (181) ?
100	*rukba dhāt al-kursī*	102;5	56;30	39;09	45;53	δ Cas (182)
101*	*aṣl dhanab qayṭus*	103;16	-12;20	07;12	-16;35	BSC 190 (731) ?
102	*shamālī al-ʿaqd*	104;2	10;27	16;58	04;04	η Psc (695) ?
103*	*rijl al-musalsala*	105;0	44;40	33;13	34;48	ϕ Per (350) ?
104	*aʿlā rijl al-maraʾa*	106;30	47;0	35;43	36;21	γ And (349) ?
105	*sāq* [*dhāt*] *al-kursī*	107;17	59;20	44;46	46;42	ε Cas (183)
106	*thānī al-ʿaqd*	108;14	5;20	18;50	-02;16	o Psc (693) ?
107*	*qarn al-ḥamal al-shamālī*	109;13	15;34	23;38	06;50	γ Ari (362)
108*	*shamālī al-naʿāmāt*	110;16	-13;42	13;12	-20;35	ζ Cet (725)
109*	*thānī al-sharaṭayn*	111;0	16;54	25;44	07;26	β Ari (363)
110*	*janūbī al-naʿāmāt*	112;56	-26;16	09;50	-33;03	υ Cet (724) ?
111*	*al-nāṭiḥ*	113;17	19;50	28;53	09;20	α Ari (375)
112	*ʿurf qayṭus*	114;6	4;20	23;54	-05;22	ξ^1 Cet (718)
113*	*ʿayn qayṭus*	115;17	-4;56	21;32	-14;25	λ Cet (712) ?
114	*janūbī mankib barshāwush*	116;0	30;10	35;13	18;00	?
115	*ʿurqūb qayṭus*	117;0	-4;21	23;24	-14;31	?
116	*shamālī ṣadr qayṭus*	118;30	-17;7	19;40	-26;53	ρ Cet (719) ?
117	*dhaqan* [MS: *dqr*] *qayṭus*	119;33	-3;45	26;05	-14;53	δ Cet (715)
118	*ḍilʿ qayṭus*	120;40	-19;14	20;52	-29;38	σ Cet (720) ?
119*	*nayyir al-buṭayn*	121;34	23;11	37;23	09;41	ε Ari (368) ?
120*	*raʾs qayṭus*	122;17	-6;41	27;38	-18;36	γ Cet (714) ?
121	*mankib barshāwūsh*	123;0	50;0	49;20	34;12	γ Per (193)
122	*ṣadr qayṭus*	124;0	-17;36	24;57	-29;22	π Cet (722) ?
123	*bayna mankib* (!) *al-ʿawwāʾ*	125;15	45;35	48;56	29;32	?
124*	*raʾs al-ghūl*	126;20	51;56	52;36	35;08	β Per (202)
125*	[*al-*]*kaff al-jadhmā*	127;16	-16;56	28;33	-29;55	α Cet (713)
126	*mirfaq barshāwūsh*	128;0	51;20	53;29	34;10	η Per (192)
127	*ākhar al-nahr*	129;0	-43;20	14;23	-54;18	θ Eri (805)
128	*nayyir barshāwush*	130;0	46;35	52;52	29;16	α Per (197)
129	*taḥt al-nahr*	131;0	-36;30	22;01	-49;07	?
130	*rābiʿ ʿashar al-nahr*	132;0	-12;35	35;11	-27;27	ζ Eri (785) ?
131	*ḥādī ʿashar al-nahr*	133;0	-24;30	31;11	-38;56	?
132	*shamālī al-qiṭʿ*	134;0	9;37	44;24	-06;57	5 Tau (380)
133	*fakhdh barshāwush*	135;0	39;30	54;08	21;23	ν Per (212)
134	*awwal al-thurayyā*	136;0	20;35	49;22	03;02	19 Tau (409) ?
135	*wasaṭ al-thurayyā*	137;0	21;7	50;25	03;17	23 Tau (410) ?
136	*ākhar al-thurayyā*	138;0	21;40	51;28	03;33	27 Tau (411) ?
137	*ʿātiq al-thurayyā*	139;0	29;0	54;19	10;23	o or ζ Per (215 or 216)
138*	*rukba barshāwush* [*al-yusrā*]	140;0	37;35	57;32	18;26	ε Per (213)

No	Name	α'	Δ	λ	β	Identification
139	*thālith ʿashar al-nahr*	141;0	-25;20	39;43	-42;19	τ^7 or τ^8 Eri (795 or 796) ?
140	*ṣadr al-thawr*	142;0	9;50	52;07	-08;52	λ Tau (385)
141	*kaʿb al-thawr al-yusrā*	143;0	3;3	51;23	-15;41	ν Tau (387)
142	*rukbat al-thawr al-yumnā*	144;0	6;7	53;09	-12;57	μ Tau (386)
143	*sāq barshāwush* [*al-yumnā*]	145;0	44;20	63;19	23;57	53 Per (210)
144	*anf al-thawr*	146;0	13;23	56;49	-06;21	γ Tau (390)
145	*thāmin al-nahr*	147;0	-9;16	52;15	-28;36	o^2 Eri (779) ?
146*	*ʿayn al-thawr* [*al-shamālī*]	148;0	15;13	59;07	-04;59	ε Tau (394)
147*	*nayyir al-dabarān*	149;0	14;50	59;59	-05;34	α Tau (393)
148	*rukbat al-thawr al-yusrā*	150;0	10;0	59;57	-10;29	90 Tau (388)
149	*sādis al-nahr*	151;0	-5;27	57;35	-25;49	ν Eri (777)
150	*wasaṭ al-nahr*	152;0	-16;0	55;56	-36;19	?
151	*sābiʿ ʿashar al-nahr*	153;0	-30;15	52;06	-50;19	υ^1 Eri (798) ?
152	*kaʿb al-aʿna*	154;0	31;27	67;42	09;52	ι Aur (229)
153	*al-ʿanz*	155;0	42;14	70;30	20;20	ε Aur (226)
154*	*rābiʿ al-nahr*	156;0	-7;24	62;37	-28;43	ω Eri (775)
155*	*ʿayyūq al-thurayyā*	157;4	44;30	72;31	22;18	α Aur (222)
156	*shamālī awwal al-nahr*	158;0	-6;17	65;04	-27;58	β Eri (773)
157	*qadam al-arnab*	159;17	-24;2	62;28	-45;39	ε Lep (811)
158*	*rijl al-jawzāʾ*	160;21	-9;43	67;04	-31;44	β Ori (768)
159*	*qarn al-thawr al-shamālī*	161;9	27;20	73;16	04;51	β Tau (230)
160	*mankib al-jawzāʾ* [*al-aysar*]	162;0	4;56	71;10	-17;28	γ Ori (736)
161	*qarn al-thawr al-janūbī*	163;0	23;8	74;24	00;28	ζ Tau (398)
162	*raʾs al-jawzāʾ*	164;19	8;47	74;01	-13;56	λ Ori (734)
163	*awwal al-naẓam*	165;0	-1;40	73;30	-24;23	δ Ori (759)
164	*sayf al-jabbār*	166;0	-7;7	73;55	-29;55	ι Ori (765)
165	*ākhar al-qurūd*	167;2	-37;3	69;13	-59;42	ε Col (846)
166*	*miʿṣam al-aʿna*	168;9	36;25	80;14	13;14	θ Aur (225)
167	*rukbat al-jawzāʾ*	169;11	-10;27	77;12	-33;33	κ Ori (771)
168*	*yad al-jawzāʾ al-sharqīya*	170;3	6;0	79;38	-17;13	α Ori (735)
169	*shamālī khārij al-arnab*	171;0	-21;15	78;13	-44;28	δ Lep (814) ?
170*	*dhanab al-arnab*	172;0	-14;55	80;09	-38;14	η Lep (817)
171	*awwal al-hanʿa*	173;54	21;55	84;20	-01;33	μ Gem (438) !
172	*al-sukkān al-shamālī*	174;17	-43;30	79;24	-66;52	η Col (890)
173	*rijl al-jawzāʾ* [*sic*! cf. no. 158!]	175;0	-12;13	83;59	-35;42	?

No	Name	α'	Δ	λ	β	Identification
174	*thānī al-hanʿa*	176;0	19;30	86;13	-04;02	ν Gem (439) !
175*	*nayyir al-hanʿa*	177;58	17;50	88;03	-05;44	γ Gem (440) ?
176	*mirzam al-ʿabūr*	178;51	-17;47	88;32	-41;22	β CMa (826)
177	*ṭaraf rijl al-kalb*	179;0	-30;12	88;32	-53;47	ζ CMa (834)
178*	*suhayl al-yaman*	180;57	-52;26	92;24	-76;01	α Car (892)
179	*qadam al-jawzāʾ*	181;59	14;30	91;57	-09;04	ξ Gem (441)
180	*rukbat al-tawʾām*	183;0	26;0	92;42	02;27	ζ Gem (434) ?
181*	*al-ʿabūr*	184;17	-15;40	95;19	-39;10	α CMa (818)
182	*tālī al-sukkān al-shamālī*	185;0	-11;36	95;59	-35;05	ν Pup (891)
183	*udhun al-kalb*	186;0	-21;36	97;54	-45;01	θ CMa (819)
184	*tālī suhayl al-yaman*	187;43	-43;45	104;20	-66;57	?
185	*suhayl al-ʿadhārā*	188;58	-23;5	101;59	-46;18	o^2 CMa (829)
186	*wasaṭ al-ʿadhārā*	189;57	-25;8	103;35	-48;15	δ CMa (831)
187*	*nayyir mankibay al-tawʾamān*	190;0	28;0	98;51	04;44	υ Gem (429) ?
188	*mirzam al-ghumayṣā*	191;56	8;54	102;10	-14;11	β CMi (847)
189*	*awwal al-dhirāʿ al-shaʾāmiya*	192;2	33;0	100;13	09;51	α Gem (424)
190	*janūbī al-kawthal*	193;4	-36;20	110;42	-58;59	π Pup (860)
191	*ākhar al-ʿadhārā*	195;4	-28;15	111;12	-50;43	η CMa (835)
192*	*al-ghumayṣā*	196;11	6;20	106;47	-16;18	α CMi (848)
193	*thānī al-dhirāʿ al-shaʾāmiya*	197;0	28;54	104;55	06;12	β Gem (425)
194	*hhārij al-kalb*	198;11	-8;0	110;58	-30;16	δ Mon (836) ?
195	*wasaṭ [farsh] al-kawthal*	199;11	-35;50	119;40	-57;27	c Pup (863) ?
196	*thānī farsh al-kawthal*	200;0	-38;20	122;07	-59;42	BSC 2961 + 2964 (862) ?
197	*ṭaraf al-safīna*	201;0	-21;25	117;09	-43;02	11 Pup (849)
198	*thānī mirfaq al-kawthal*	202;0	-38;20	125;05	-59;15	a Pup (866) ?
199*	*rijl al-saraṭān [al-janūbī]*	203;11	11;20	113;06	-10;24	β Cnc (457)
200	*muqaddam lisān al-shujāʿ*	204;0	-1;0	116;06	-22;25	?
201	*taḥt al-farsh*	205;58	-45;25	136;20	-64;51	γ Vel (883)
202*	*lisān al-shujāʿ*	206;51	2;56	118;19	-18;02	?
203	*mubdāʾ al-safīna*	207;9	-53;0	148;03	-71;07	χ Car (884) ?
204	*awwal al-nathra*	209;54	21;0	117;44	00;16	NGC 2632 (449)
205	*ākhar al-nathra*	210;51	20;16	118;45	-00;16	δ Cnc (453)
206	*janūbī raʾs al-shujāʿ*	211;12	4;45	122;22	-15;23	σ Hya (894)
207	*shamālī al-qafzat al-ūlā*	212;0	50;0	112;54	28;57	ι UMa (20) !
208	*janūbī al-qafzat al-ūlā*	213;11	48;53	114;04	28;03	κ UMa (21) !

No	Name	α'	Δ	λ	β	Identification
209	*raʾs al-shujāʿ*	214;12	8;10	124;35	-11;23	ε Hya (896) ?
210	*dhaqan* [MS: *dqr*] *al-shujāʿ*	215;13	8;0	125;37	-11;19	ζ Hya (898)
211*	*mutaqaddam al-ẓibāʾ* [MS: *al-ḍibā*]	216;11	42;52	117;59	22;45	BSC 3809 or 3612 (41) ?
212	*wasaṭ al-safīna*	217;0	-51;30	159;10	-66;22	δ Vel (886) ?
213	*shamālī al-ḍibā*	218;15	39;18	120;35	19;43	38 Lyn (39) ?
214	*ʿunq al-dubb*	219;11	66;31	111;10	45;48	τ UMa (15)
215	*janūbī al-ḍibā*	220;9	36;38	122;52	17;33	α Lyn (38) ?
216	*janūbī jabhat al-asad*	221;6	28;2	126;02	09;28	?
217*	*raqabat al-dubb*	222;0	54;40	118;15	35;09	23 UMa (16) ?
218	*shamālī al-ṭaraf*	223;11	24;50	128;44	06;54	λ Leo (463) ?
219*	*suhayl al-farad*	223;9	6;2	133;53	-11;11	?
220	*ṣadr al-dubb*	224;11	12;10!	133;09	-05;01	23 or υ UMa (16 or 17) ?
221	*janūbī al-ṭaraf*	225;0	21;36	131;15	04;16	?
222	*shamālī raqabat al-shujāʿ*	226;11	36;30	127;47	18;49	ω Hya (899) ?
223	*janūbī raʾs al-asad*	227;0	25;13	131;57	08;15	ε Leo (465) ?
224	*wasaṭ al-shujāʿ*	228;0	-11;46	144;31	-26;41	κ or υ^1 Hya (906 or 907) ?
225	*ākhar al-safīna*	229;9	-53;43	175;53	-63;20	N Vel (889)
226	*rukbat al-asad*	230;51	12;3	139;26	-03;12	π Leo (475)
227*	*qalb al-asad*	231;58	14;24	139;44	-00;37	α Leo (469)
228*	[*shamālī*] *al-qafza al-thālitha* [read: *al-thāniya*]	232;57	45;30	129;46	29;00	λ UMa (28) !
229	*shamālī raqabat al-asad*	233;59	26;20	137;40	11;17	ζ Leo (466)
230	*wasaṭ raqabat al-asad*	234;51	23;20	139;25	08;43	γ Leo (467)
231	*ākhar al-jabha*	235;58	22;0	140;51	07;48	η Leo (468) ?
232	*janūbī al-qafza al-thālitha* [read: *al-thāniya*]	236;0	43;33	132;53	27;59	μ UMa (29) !
233*	*baṭn al-shujāʿ*	237;51	-14;3	155;24	-25;24	μ Hya (909) ?
234	*ibṭ al-asad*	238;51	11;58	146;51	-00;43	ρ Leo (476)
235	*muqaddam thalāthat al-shujāʿ al-awwal*	239;0	-14;10	156;36	-25;06	μ Hya (909) ?
236	*taḥt al-shujāʿ*	240;0	-16;0	158;22	-26;25	ϕ Hya (910) ?
237	*sābiʿ ʿashar al-nahr*	241;40	-13;10	158;48	-23;11	BSC 859 or 784 (788) ?
238	*ẓahr al-shujāʿ*	242;51	-13;21	160;02	-22;54	ν Hya (911) ?
239	*ẓahr al-dubb*	243;58	64;30	125;54	48;44	α UMa (24)
240	*qaṭan al-asad*	244;59	23;14	148;19	11;54	60 Leo (480)
241	*awwal al-bāṭiya*	245;38	-15;18	163;34	-23;39	α Crt (921)
242*	*awwal al-khurtān*	246;57	23;43	149;51	13;01	δ Leo (481)

No	Name	α'	Δ	λ	β	Identification
243	*thānī al-khurtān*	248;58	18;23	153;40	08;47	θ Leo (483)
244	*janūbī al-qafza al-thālitha*	249;51	34;45	147;43	24;09	ξ UMa (32) !
245	[*al-*]*shamālī* [*min al-ithnayn alladhīn fī wasṭ*] *al-bāṭiya*	250;58	-12;5	167;17	-18;38	δ Crt (923)
246	*fakhdh al-asad*	251;34	13;28	157;53	05;11	ι Leo (484)
247	[*al-*]*janūbī* [*min al-ithnayn alladhīn fī wasṭ*] *al-bāṭiya*	252;15	-14;13	169;25	-20;05	γ Crt (922)
248	*rijl al-asad al-yusrā*	253;58	14;30	159;39	07;02	?
249	*muqaddam thalāthat al-shujāʿ al-thānī*	254;51	-29;50	179;24	-33;08	ξ Hya (914) ?
250*	*wasaṭ thalāthat al-shujāʿ*	255;1	-30;50	180;07	-33;57	o Hya (915)
251*	*janūbī fakhdh al-dubb*	256;51	52;5	143;26	41;51	?
252*	*al-ṣarfa wa-hiya dhanab al-asad*	257;58	18;40	161;33	12;22	β Leo (488)
253	*tālī thalāthat al-shujāʿ*	258;51	-24;40	180;23	-26;55	ξ Hya (914) ?
254	*awwal al-ʿawwāʾ*	259;56	3;0	169;34	-01;15	β Vir (501)
255	*janūbī wajh al-sunbula*	260;51	9;0	168;02	04;37	π Vir (500)
256	*shamālī wajh al-sunbula*	261;58	11;40	167;59	07;30	o Vir (499)
257*	*minqār al-ghurāb*	262;59	-20;50	182;19	-21;49	α Crv (928)
258*	*janāḥ al-ghurāb al-ayman*	263;51	-13;55	180;03	-15;11	γ Crv (931)
259	*thānī al-ʿawwāʾ*	265;58	2;30	175;18	00;41	η Vir (502)
260	*maʾbiḍ* [MS: *mābiṭ*] *qanṭūris al-ayman*	266;8	-55;30	207;33	-50;24	γ Cru (965)
261	*janāḥ al-ghurāb al-aysar*	267;58	-13;31	183;39	-13;11	δ Crv (932)
262	*rijl al-ghurāb al-ayman*	268;49	-19;33	187;01	-18;20	β Crv (934)
263	*kaʿb qanṭūris*	269;51	-53;31	208;18	-47;31	β Cru (966)
264	*qaṭn qanṭūris*	270;58	-44;20	202;07	-39;28	γ Cen (957)
265	*zāwiyat al-ʿawwāʾ*	271;18	2;20	180;15	02;40	γ Vir (503)
266	[*bi-*]*qurb dhanab al-tinnīn*	272;0	72;13	129;26	61;17	κ Dra (73)
267	*rābiʿ al-ʿawwāʾ*	273;51	8;28	180;07	09;18	δ Vir (506)
268	*janb al-sunbula*	274;51	8;30	181;01	09;43	?
269*	*kabid al-asad*	275;58	41;40	165;18	39;49	α CVn (36)
270*	*ākhar al-ʿawwāʾ*	276;48	15;5	180;02	16;31	ε Vir (509)
271	*al-jawn min al-dubb*	277;0	60;0	149;39	54;54	ε UMa (33)
272	*mutaqaddam al-aʿzal*	278;51	-2;5	188;57	01;37	θ Vir (505) ?
273	*mankib qanṭūris al-aysar*	279;58	-32;2	202;33	-25;18	ι Cen (939)

No	Name	α'	Δ	λ	β	Identification
274	*asl dhanab al-shujāʿ*	280;59	-19;22	197;48	-13;25	γ Hya (917)
275*	*al-simāk al-aʿzal*	281;58	-7;5	193;46	-01;46	α Vir (510)
276	*al-ʿanāq*	282;51	59;0	154;39	56;15	ζ UMa (34)
277	*ibṭ qanṭūris*	283;51	-50;12	215;46	-40;00	M Cen (962)
278	*ḥurqufat* [*sic*: should be *ḥarqafat*] *al-sunbula*	284;0	3;20	191;33	08;37	ζ Vir (511)
279	*aʿlām al-simāk*	285;51	86;24	98;57	67;09	?
280	*janb qanṭūris*	286;59	-34;17	209;28	-24;49	ν Cen (946) ?
281	*badan qanṭūris*	287;51	-43;12	214;36	-32;33	ζ Cen (952)
282	*janūbī sāq al-ʿawwāʾ*	288;59	19;40	189;19	25;32	υ Boo (109)
283	*tālī janb qanṭūris*	289;0	-37;40	212;43	-27;11	ϕ Cen (948) ?
284	*rumḥ al-rāmiḥ*	290;57	22;5	190;02	28;30	η Boo (107)
285	*fakhdh al-sunbula*	291;59	4;14	198;41	12;32	90 Vir (517) ?
286*	*dhanab al-shujāʿ*	292;2	-24;5	209;25	-13;42	π Hya (918)
287*	*wasaṭ al-ghafr*	293;59	-6;37	204;38	03;12	κ Vir (519)
288*	*shamālī al-ghafr*	294;55	-1;57	203;47	07;53	ι Vir (518)
289	*janūbī al-ghafr*	295;9	-9;9	206;38	01;16	λ Vir (521)
290*	*al-simāk al-rāmiḥ*	296;11	24;40	193;49	32;53	α Boo (110)
291	*sāʿid qanṭūris*	297;58	-38;50	220;24	-25;22	η Cen (950)
292	*minṭaqat al-ʿawwāʾ*	298;59	33;39	191;29	42;00	σ Boo (104) ?
293*	*mankib al-ʿawwāʾ* [*al-aysar*]	299;51	41;30	186;43	49;09	γ Boo (92)
294	*qadam al-sunbula*	300;59	-2;2	209;33	09;59	μ Vir (522)
295	*ʿuqb al-ʿawwāʾ*	302;9	17;40	203;03	28;45	ζ Boo (106)
296*	*janūbī al-zubānā*	303;54	-12;30	215;51	01;07	α Lib (529)
297*	*fakhdh al-ʿawwāʾ*	304;39	30;32	199;07	41;25	ε Boo (103)
298	*rijl qanṭūris*	305;32	-58;0	235;15	-40;51	α Cen (969)
299	*ʿālī al-zubānā*	306;49	-5;42	216;21	08;29	δ Lib (532) ?
300	*badan al-sabʿ*	307;58	-41;25	229;18	-24;57	ε Lup (976)
301	*kitf al-sabʿ*	308;51	-36;25	228;10	-20;00	δ Lup (974)
302*	*shamālī al-zubānā*	309;48	-5;42	219;12	09;26	β Lib (531)
303	*wasaṭ al-zubānā* [*al-shamālī*]	310;51	-20;23	224;41	-04;14!	γ Lib (535) ?
304*	*mankib al-ʿawwāʾ al-ayman*	311;37	36;20	202;49	49;12	δ Boo (94)
305	*tālī kitf al-sabʿ*	312;59	-38;22	232;09	-20;48	γ Lup (975)
306	*shamālī al-fakka*	304;55	32;25	198;15	43;12	?
307*	*nayyir al-fakka*	316;0	30;5	211;36	45;06	α CrB (111)
308*	*ʿunq al-ḥayya*	317;7	8;58	221;48	25;37	α Ser (271)
309	*al-dhīkh*	318;0	41;45	205;50	56;19	ι Dra (70]) ?
310	*awwal al-iklīl*	319;0	-23;15	232;47	-04;50	π Sco (548)
311	*thānī al-iklīl*	320;14	-19;45	232;59	-01;10	δ Sco (547)
312	*ākhar al-iklīl*	321;9	-17;20	233;12	01;24	β Sco (546)
313	*ākhar jabhat al-ʿaqrab*	323;51	-17;3	235;38	02;18	ν Sco (550) ?
314	*al-niyāṭ al-awwal*	325;7	-23;4	238;12	-03;16	σ Sco (552)

No	Name	α'	Δ	λ	β	Identification
315	*tālī kitf al-ḥawwāʾ*	326;11	-2;43	234;30	16;46	γ or κ Oph (236 or 238) ?
316*	*qalb al-ʿaqrab*	327;8	-24;5	240;14	-03;51	α Sco (553)
317	*ʿaḍad al-jāthī* [*al-yumnā*]	328;11	21;43	229;36	40;55	γ Her (121)
318	*al-niyāṭ al-thānī*	329;0	-25;40	242;13	-05;02	τ Sco (554)
319*	*mirfaq al-jāthī*	330;0	4;3	236;51	24;14	κ or μ Her (122 or 125) ?
320	*al-sābiq al-awwal*	331;0	-14;0	241;43	06;46	ζ Oph (252)
321	*al-kharazat al-ūlā*	332;0	-31;54	246;05	-10;38	ε Sco (557)
322	*al-kharazat al-thāniya*	333;0	-36;24	247;47	-14;53	μ Sco (558)
323	*shamālī fakhdh al-jāthī* [*al-ayman*]	334;0	44;33	224;26	64;03	σ Her (142)
324	*janb al-jāthī al-ayman*	335;0	33;28	233;16	53;53	ζ Her (129)
325	*fakhdh al-jāthī al-ayman*	336;2	40;4	230;58	60;25	η Her (141)
326	*mankib al-jāthī al-aysar*	337;4	9;56	243;17	31;24	δ Her (123) ?
327	*wasaṭ al-mijmara*	338;0	-48;45	254;00	-26;23	α Ara (993)
328*	*al-sābiq al-thānī*	338;0	-15;13	248;39	06;45	η Oph (245)
329	*janb al-jāthī al-aysar*	339;3	32;52	239;06	54;13	ε Her (130)
330	*awwal al-shawla*	340;46	-36;30	254;10	-13;58	λ Sco (565)
331	*thānī al-shawla*	341;56	-36;50	255;10	-14;11	υ Sco (566)
332	*al-kharazat al-khāmisa*	342;4	-42;22	256;01	-19;39	θ Sco (562)
333	*fakhdh al-jāthī al-aysar*	343;9	38;23	242;39	60;22	π Her (133)
334	*al-kharazat al-sābiʿa*	344;8	-38;0	257;06	-15;08	κ Sco (564)
335	*al-kharazat al-sādisa*	345;0	-39;30	257;59	-16;33	ι^1 Sco (563)
336*	*raʾs al-ḥawwāʾ*	346;0	13;30	253;02	36;15	α Oph (234)
337*	*mankib al-ḥawwāʾ* [MS: *al-jawzāʾ* !] *al-ayman*	347;9	5;30	255;25	28;26	β Oph (235)
338	*al-dhiʾb al-awwal*	348;3	66;22	175;07	85;13	ζ Dra (67)
339*	*ʿayn al-tinnīn*	349;6	53;23	242;23	75;55	β Dra (46)
340	*kaff al-ḥawwāʾ al-ayman*	350;0	[-]9;30	259;51	13;44	ν Oph (243)
341	*awwal al-naʿāʾim al-wārida*	351;0	-9;30	260;52	13;48	η Sgr (594)
342	*al-rāqiṣ*	352;0	45;0	254;40	68;09	μ Dra (44)
343*	*wasaṭ miʿṣam al-jāthī* [*al-aysar*]	353;0	28;46	259;59	52;06	o Her (126)
344	*rukbat al-jāthī* [*al-yusrā*]	354;0	37;43	260;09	61;06	θ Her (136)
345	*al-ẓalīm al-janūbī*	355;0	-20;38	265;19	02;52	μ Sgr (574)
346	*miʿṣam al-jāthī*	355;48	28;24	264;00	51;54	ξ Her (128) ?

No	Name	α'	Δ	λ	β	Identification
347	*al-rāʿī*	356;9	-25;0	266;31	-01;28	λ Sgr (573)
348	*aṣl dhanab al-ḥayya*	357;0	-7;15	266;54	16;18	η Ser (279)
349	*taḥt al-ḥayya*	358;0	-9;2	267;58	14;32	τ Oph (244)
350	*awwal al-naʿāʾim al-ṣādira*	360;0	-27;25			same as no. 1

Post-scriptum to the table (**B**:151r)

اعلم وفّقك اللّه تعالى أنّ المطالع والأبعاد لهذه الكواكب المذكورت نقلتُها تقليدًا لا رصدًا ولم اجد لبداية أرصادها تأريخًا معلومًا ولم يكن ذلك عجز من طريق العلم ولاكن تحتاج إلى فراغ كثير وهو في زمننا هذا عسير فمن كان من أهل الاجتهاد فعليه بحسن الارتعاد (؟ / الارتصاد ؟) فقد ذكروا (!) العلماء المجتهدين (!) الراصدين (!) أنّ المطالع تزداد في كلّ سبعين سنة درجة واحدة يكون ذلك في كلّ سنة أحد وخمسين ثانية تقريبًا فمن أراد رصدها فليؤرّخ مبداء ذلك ويذكر الزيادة المذكورة وأمّا الأبعاد تحتاج تحقيق أبعادها وجهة أبعادها من غير تاريخ ولا زمان ولا زيادة ولا نقصان فافهم تصب إن شاء اللّه تعالى

Be aware — may God the Very High grant you success! — that I got the right ascensions and declinations of the above-mentioned stars by copying (them), not by observation. I could not find a specific epoch corresponding to the beginning of the (underlying) observations. This is not due to a failure of the scientific method, but you need a lot of spare time, which is difficult in these days of ours. Whoever happens to be a person of judgment, it is his duty to ...... (?). The scholars of sound judgment who carried observations had mentioned that the right ascension (*sic*!) increases each seventy years of one degree, which is approximately fifty-one seconds per year. Whoever wants its observation (*sc.* its epoch), let him calculate the epoch date, bearing in mind the above-mentioned increment. As for the declinations, you need to find (the values of) their declinations and their signs (from the table), without (having to consider) neither an epoch, a time (*sc.* your date), an augmentation nor a diminution. Understand this and you will get it right.

C.2 *Stars featured on the illustrations of retes*

The following is a list of the stars featured on the illustrations of retes in Najm al-Dīn's instrument treatise, arranged by chapter. The numbers refer to the above table. The order – as in the edition of the Arabic text – corresponds to increasing right ascension as measured on the illustration, starting with Aries.

Ch. 1 — (Northern projection) 91, 147, 158, 181, 192, 227, 290, 307, 316, 336, 4, 19, 37, 48.

Ch. 9:[4] Northern projection: 290, 293, 308, 336, 4, 19, 37. Southern projection: 296, 48, 66.

Ch. 11 — Northern projection: 86[5], 147, 158, 227, 233, 275, 307, 316, 19, 37, 69, 48.

Ch. 12:[6] Northern projection: 86*[7], 124, 181*, 251, 290, 296*, 48*, 69. Southern projection: 109, 147*, 175*, 192*, 227*, 252*, 308*, 336*, 19*, 68*, 72*.

Ch. 14 — Northern projection: 91, 111, 124, 147, 158, 181, 219, 252, 275, 290, 308, 307, 336, 4, 19, 37, 69. Southern projection: 227, 9.

Ch. 15 (see Plate 17) — (Extended southern projection) 90, 91, 96, 103, 119, 124, 125, 138, 154, 155, 159, 168, 166, 181, 178, 187, 189, 217, 233, 227, 228, 242, 250, 251, 269, 270, 290, 293, 308, 297[8], 307, 304[9], 339, 343, 4[10], 16, 19, 21[11], 37, 30[12], 57, 69, 66, 79, 85, 84.

Ch. 17 — (Northern projection) 91, 120, 147, 155, 158, 168, 181, 192, 219, 227, 233, 257, 86.

Ch. 18 — Northern projection: 168, 175, 258, 275, 302, 4, 69. Southern projection: 109, 110, 219, 19, 68.

Ch. 19[13] — (Northern projection) 275, 302, 337, 336, 11, 19, 68, 109, 168, 181, 219, 258.

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[4] Curiously only stars with right ascensions in the interval $180° \leq \alpha \leq 360°$ have been chosen, and their positions are as if the astrolabe were of the regular myrtle type, thus being unrelated to the irregular disposition of the signs on the rete.

[5] The position actually corresponds to no. 91.

[6] The numbers marked with an asterisk indicate that the associated projection is incorrectly given in the text.

[7] The position is incorrect.

[8] Incorrect position.

[9] Incorrect position.

[10] The radius is too large.

[11] Radius too large.

[12] Incorrect position.

[13] The stars are projected as on a standard northern astrolabe turned upside-down, and their right ascensions are independent of the weird arrangement of the zodiacal signs (on this rete $\alpha = 0$ corresponds to the beginning of Cancer, on the right-hand side).

Ch. 20 — (Northern projection) 108, 158, 192, 257, 286, 302, 336, 19, 68[14], 86.

Ch. 21 — Northern projection: 258, 275, 19[15], 86[16]. Southern projection: 107, 158[17], 68.

Ch. 22 — Northern projection: 101, 168, 258, 275, 19. Southern projection: 202, 319[18], 72.

Ch. 23 — Northern projection: 86[19], 107, 138(?)[20], 168, 192, 219, 275, 319, 336, 84. Southern projection: 252, 19, 72.

Ch. 24[21] — 211(?)[22], 336, 19, 4, 48, 101.

Ch. 27 — Northern projection: 147, 158, 192, 219, 275, 31. Southern projection: 252, 302, 336, 19, 84.

Ch. 28 — Northern projection: 275. Southern projection: 168, 19[23], 252, 336, 19, 84.

Ch. 33[24] — Northern projection: 181, 290, 336, 19. Southern projection: 175, 192[25], 68, 86.

Ch. 34 — (Northern projection) 101, 108, 113, 120, 125, 158[26], 170, 181, 192, 250[27], 147[28], 258, 275, 288[29], 287, 296, 316, 336, 328, 25, 19, 48,

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[14] The right ascension is incorrect and the radius corresponds to a southern projection (which was probably not intended).

[15] There is a decorative pointer marked ٢, symmetrically opposite to this one with respect to the horizontal diameter.

[16] There is a decorative pointer symmetrically opposite this one with respect to the horizontal diameter.

[17] There is a decorative pointer marked ٢, symmetrically opposite to this one with respect to the horizontal diameter.

[18] Inaccurate position.

[19] Wrong position.

[20] The star is simply labelled *barshāwush*. This could stand for *rukba barshāwush* (no. 138), which is already featured in Ch. 15. The position of the pointer, however, fits the coordinates of *mankib barshāwush* (no. 121) or *mirfaq barshāwush* (no. 126) better.

[21] The positions of the stars-pointers for nos. 336, 4, 19 and 48 correspond to a standard northern projection. That of no. 101 is symmetrically opposite its natural location with respect to the horizontal diameter.

[22] If the reading *nayyir al-ẓibāʾ* is correct (the table has incorrectly *al-ḍibāʾ*), then this could be one of nos. 211, 213 or 215, and the star-pointer would be 90° anticlockwise from its expected position. Note that a confusion with *nayyir al-khibāʾ* (Ch. 34) is possible, but the position of the pointer makes this very unlikely.

[23] This star-pointer is diametrically opposite to a second one with the same star-name! The latter corresponds to the correct position of this star.

[24] Stars 290 and 86 are associated with the myrtle rete and their position is accordingly displaced by 180°.

[25] The right ascension is displaced 90° anticlockwise.

[26] The radius would better fit a southern projection, but since all other star-pointers are in northern projection, this must also be northern (with radius too short).

[27] Inaccurate position.

[28] Wrong position.

[29] Inaccurate position.

56/58/60[30], 86.

Ch. 35 — (Northern projection) 101, 146, 158, 4[31], 192, 227, 37[32], 258, 275, 290, 307, 336, 19[33], 36, 252[34], 86.

Ch. 36 — Northern projection: 146, 227, 287, 307, 336, 19, 37, 86. Southern projection: 178.

Ch. 37 — Northern projection: 146, 181, 227, 275, 336, 19, 86. Southern projection: 199[35], 175, 252.

Ch. 38 — (Northern projection) 336[36], 19.

C.2.1 *Concordance star number → chapters*

88 different stars are featured on the illustrations of retes in Najm al-Dīn's treatise. The following list gives, for each of them, the chapters in which they occur. The numbers in square brackets refer to astrolabe star numbers in the following publications:
A = List of astrolabe stars in Kunitzsch 1959, pp. 65–86.
S = List in Kunitzsch 1990.

4 [A53/S4]: 1, 9, 14, 15, 18, 24, 35 **9**: 14 **11**: 19 **16**: 15 **19** [A54/S13]: 1, 9, 11, 12, 14, 15, 18, 19, 20, 21, 22, 23, 24, 27, 28, 28, 33, 34, 35, 36, 37, 38 **21**: 15 **25**: 34 **30**: 15 **31** [A55/S14]: 27 **36**: 35 **37** [A56/S6]: 1, 9, 11, 14, 15, 35, 36 **48** [A58/S19]: 1, 9, 11, 12, 24, 34 **56/58/60**: 34 **57**: 15 **66** [A61/S33]: 9, 15 **68** [A63/S18]: 12, 18, 19, 20, 21, 33 **69** [A62/S17]: 11, 12, 14, 15, 18 **72**: 12, 22, 23 **79**: 15 **84** [A1/S15]: 15, 23, 27, 28 **85**: 15 **86** [A4/S35]: 11, 12, 17, 20, 21, 23, 33, 34, 35, 36, 37 **90**: 15 **91**: 1, 14, 15, 17 **96** [A7/S20]: 15 **101** [S53]: 22, 24, 34, 35 **103** [A10/S21]: 15 **107**: 21, 23 **108**: 20, 34 **109**: 12, 18, 19 **110**: 18 **111** [A11/S54]: 14 **113**: 34 **119**: 15 **120**: 17, 34 **124** [A14/S9]: 12, 14, 15 **125** [A13/S34]: 15, 34 **138**: 15, 23(?) **146**: 35, 36, 37 **147** [A18/S24]: 1, 11, 12, 14, 17, 27, 34 **154**: 15 **155** [A20/S10]: 15, 17 **158** [A19/S37]: 1, 11, 14, 17, 20, 21, 27, 34, 35 **159**: 15 **166**: 15 **168** [A22/S36]: 15, 17, 18, 19, 22, 23, 28 **170**: 34 **175** [K28]: 12, 18, 33, 37 **178**: 15, 36 **181** [A23/S39]: 1, 12, 14, 15, 17, 19, 33, 34, 37 **187** [A26?]: 15 **189**: 15 **192** [A25/S40]: 1, 12, 17, 20, 23, 27, 33, 34, 35 **199**: 37 **202**: 22 **211**: 24(?) **217**: 15 **219** [A29/S42?]: 14, 17, 18, 19, 23, 27 **227** [A30/S26]: 1, 11, 12,

[30] The star-pointer is labelled *nayyir al-khibāʾ*, which could refer to any of those three stars.
[31] The right ascension is displaced by 180°.
[32] The right ascension is displaced by *ca.* 180°.
[33] The radius is too large.
[34] The right ascension is displaced by 180°.
[35] Displaced 90° anticlockwise.
[36] The radius is too small.

14, 15, 17, 35, 36, 37 **228**: 15 **233**: 11, 15, 17 **242**: 15 **250**: 15, 34 **251**: 12, 15 **252** [A35/S28]: 12, 14, 23, 27, 28, 35, 37 **257**: 17, 20 **258** [A36/S43]: 18, 19, 21, 22, 34, 35 **269**: 15 **270**: 15 **275** [A39/S29]: 11, 14, 18, 19, 21, 22, 23, 27, 28, 34, 35, 37 **286**: 20 **287**: 34, 36 **288**: 34 **290** [A41/S1]: 1, 9, 12, 14, 15, 33, 35 **293**: 9, 15 **296**: 9, 12, 34 **297**: 15 **302**: 18, 19, 20, 27 **304**: 15 **307** [A45/S2]: 1, 11, 14, 15, 35, 36 **308** [S12]: 9, 12, 14, 15 **316** [A48/S30]: 1, 11, 34 **319**: 22, 23 **328**: 34 **336** [A51/S11]: 1, 9, 12, 14, 19, 20, 23, 24, 27, 28, 33, 34, 35, 36, 37, 38 **337**: 19 **339**: 15 **343**: 15.

BIBLIOGRAPHY

Ackermann 1998 = Silke Ackermann (ed.), *Humphrey Cole: Mint, Measurement and Maps in Elizabethan England* (London: British Museum, Occasional Paper No. 126).

Ackermann & Cherry 1999 = Silke Ackermann and John Cherry, "Richard II, John Holland and Three Medieval Quadrants", *Annals of Science* 56, 3–23.

Ahlwardt, *Verzeichnis* = W. Ahlwardt, *Die Handschriften-Verzeichnisse der königlichen Bibliothek zu Berlin. 5. Band: Verzeichniss der arabischen Handschriften* (Berlin, 1893).

Alf layla wa-layla = *The Thousand and One Nights* = *Alf layla wa-layla*, ed. Muhsin Mahdi, 3 vols. (Leiden: Brill, 1984).

Anagnostakis 1984 = Christopher Anagnostakis, *The Arabic Version of Ptolemy's* Planisphærium, Ph. D. thesis, Yale University.

Anagnostakis 1987 = —, "How to divide the ecliptic circle on the astrolabe", in Berggren and Goldstein 1987, pp. 133-144.

Arberry, *Catalogue* = A. J. Arberry *et al.*, *The Chester Beatty Library: A Catalogue of the Persian Manuscripts and Miniatures* (Dublin, 1959).

Archinard 1990 = Margarida Archinard, "The Diagram of Unequal Hours", *Annals of Science* 47, 173–190.

ʿAzzāwī 1958 = ʿAbbās ʿAzzāwī, *Taʾrīkh ʿilm al-falak fī ʾl-ʿIraq wa-ʿalāqātihi bi-al-aqṭār al-Islāmiyya wa-ʾl-ʿArabiyya fī ʾl-ʿuhud al-tāliya li-ayyām al-ʿAbbāsiyyīn* (Baghdad).

Badawi & Hinds 1986 = *A Dictionary of Egyptian Arabic*, ed. El-Said Badawi and M. Hinds (Beirut: Librairie du Liban).

al-Baklamīshī, *Ghunyat al-rāmī* = Ṭubayq [*sic*! should be Ṭaybughā] al-Ashrafī al-Baklamīshī, *Ghunyat al-rāmī wa-ghāyat al-marāmī fī ʿilm al-ramy ʿan al-qaws*, ed. ʿAbd al-Qādir al-Ẓāhirī (Amman: Dar ʿAmmār, 1999).

al-Battānī, *Zīj* = *Al-Battānī sive Albategnii Opus Astronomicum*, ed. Carlo Alfonso Nallino, 3 vols. (Milan, 1899–1907).

Bellosta and Rashed 2000 = Hélène Bellosta and Roshdi Rashed, *Ibrāhīm ibn Sinān: Logique et géométrie au Xe siècle* (Leiden: E. J. Brill).

Berggren 1986 = J. Lennart Berggren, *Episodes in the History of Mathematics in Medieval Islam* (New York: Springer-Verlag).

Berggren 1991 = —, "Medieval Islamic Methods for Drawing Azimuth Circles on the Astrolabe", *Centaurus* 34, 309–344.

Berggren 1994 = —, "Abū Sahl al-Kūhī's Treatise of the Astrolabe With Proof: Text, Translation and Commentary", *Physis: Rivista Internazionale di Storia della Scienza* N.S. 31, 141–252.

Berggren & Goldstein 1987 = *From Ancient Omens to Statistical Mechanics: Essays on the Exact Sciences presented to Asger Aaboe*, ed. J. L. Berggren and B. R. Goldstein (Copenhagen: Copenhagen University Library). [Acta Historica Scientiarum Naturalium et Medicinalium, 39].

Bergmann 1985 = Werner Bergmann, *Innovationen im Quadrivium des 10. und 11. Jahrhunderts – Studien zur Einführung von Astrolab und Abakus im lateinischen Mittelalter* (Stuttgart: Steiner). [Sudhoffs Archiv, Beiheft 26].

Berkey 1992 = Jonathan Berkey, *The Transmission of Knowledge in Medieval Cairo. A Social History of Islamic Education* (Princeton: Princeton University Press).

Bion 1758 = Nicolas Bion, *The Construction and Principal Uses of Mathematical Instruments*, translated by E. Stone, 2nd ed. (London; repr. London: Holland Press, 1972). [Original title: *Traité de la construction et principaux usages des instruments de mathématiques* (Paris, 1709; 5th ed. 1752).]

al-Bīrūnī, *Istīʿāb* = al-Bīrūnī, *Istīʿāb al-wujūh al-mumkina fī ṣanʿat al-asturlāb* ed. Muḥammad Akbar Jawādī al-Ḥusanī (Mashhad, 1380 Hijra shamsi [2001/2]).

al-Bīrūnī, *Taḥdīd* = al-Bīrūnī, *Kitāb Taḥdīd Nihāyāt al-Amākin*, ed. P. Bulgakov (Cairo, 1962). [English translation by Jamil Ali, *The Determination of the Coordinates of Cities ... by al-Bīrūnī* (Beirut, 1968).]

al-Bīrūnī, *Shadows* = *The Exhaustive Treatise on Shadows by Abū al-Rayḥān Muḥammad ibn Aḥmad al-Bīrūnī*, translation and commentary by E. S. Kennedy, 2 vols. (Aleppo: Institute for the History of Arabic Science, 1976).

Blau 1966 = Joshua Blau, *A Grammar of Christian Arabic, Based Mainly on South-Palestinian Texts From the First Millennium* (Louvain: Secrétariat du CorpusSCO).

Blau 1988 = —, *Studies in Middle Arabic and its Judaeo-Arabic Variety* (Jerusalem: Magnes Press).

Brentjes, "Respectability" = Sonja Brentjes, "Welcomed to the *marātib al-ʿulūm* literature, but banned from the madrasa? On the respectability, contents, and professional space of the so-called 'rational sciences' in Muslim societies between 1100 and 1700", unpublished typescript, 2001.

Brockelmann, *GAL* = Carl Brockelmann, *Geschichte der arabischen Literatur*, 2nd ed., 2 vols. (Leiden: Brill, 1943–1949); Supplementbände, 3 vols. (Leiden: Brill, 1937–1942).

Buchner 1971 = E. Buchner, "Antike Reiseuhren", *Chiron* 1, 457–482.

Calvo 1990 = Emilia Calvo, "La lamina universal de ʿAli b. Jalaf (s. XI) en la versión alfonsí y su evolución en instrumentos posteriores", in *Ochava espera* (Barcelona), pp. 221–238.

Calvo 1993 = —, *Ibn Bāṣuh: Risālat al-ṣafīḥa al-ǧāmiʿa li-ǧamīʿ al-ʿurūd: tratado sobre la lamina general para todas las latitudes* (Madrid: Consejo Superior de Investigaciones Científicas, Instituto de Cooperación con el Mundo Árabe).

Calvo 1996 = "Ibn Bāṣo's Astrolabe in the Maghrib and East", in Casulleras and Samsó 1996, II, pp. 755–767.

Cannobio 1976 = Ernesto Cannobio, "An important fragment of a West Islamic spherical astrolabe", *Annali dell' Istituto e Museo di Storia della Scienza di Firenze* 1, 37–45.

Carra de Vaux 1895 = Bernard Carra de Vaux, “L’astrolabe linéaire ou bâton d’et-Tousi”, *Journal asiatique* 9e série 5, 464–516.

Carra de Vaux 1921–26 = —, *Les penseurs de l’Islam* 5 vols. (Paris: Geuthner).

Carandell 1984 = Joan Carandell, “Trazado de las curvas de oración en los cuadrantes horizontales en la Risāla fi ʿilm al-zilāl de Ibn al-Raqqām”, *Dynamis* 4, 23–32.

Carandell 1988 = —, *Risāla fī ʿilm al-ẓilāl de Muḥammad Ibn al-Raqqām al-Andalusī* (Barcelona: Universidad de Barcelona, Instituto “Millás Vallicrosa” de Historia de la Ciencia Árabe).

Casanova 1923 = Paul Casanova, “La montre du sultan Noûr ad-Dîn (554 de l’Hégire = 1159/60)”, *Syria. Revue d’art oriental et d’archéologie* 4, 282–299; repr. in Sezgin, *AIOS*.

Casulleras 1996 = Josep Casulleras, “El último capítulo del *Kitāb al-Asrār fī natā’iǰ al-afkār*” in Casulleras and Samsó 1996, II, pp. 613–653.

Casulleras & Samsó 1996 = *From Baghdad to Barcelona. Studies in the Islamic Exact Sciences in Honour of Prof. Juan Vernet*, 2 vols. (Barcelona: Universidad de Barcelona, Instituto “Millás Vallicrosa” de Historia de la Ciencia Árabe).

Caussin 1804 = Jean Jacques Caussin de Perceval, “Le livre de la grande table hakémite, observée par . . . ebn Iounis”, *Notices et extraits des manuscrits de la Bibliothèque Nationale* 7, 16–240.

Celentano 1982 = Guiseppe Celentano, *L’epistola di al-Kindī sulla sfera armillare* (Naples: Istituto Orientale di Napoli) [Supplemento n. 33 agli ANNALI, vol. 42, fasc. 4].

Charette 1998 = François Charette, “A Monumental Medieval Table for Solving the Problems of Spherical Astronomy for All Latitudes", *Archives Internationales d’Histoire des Sciences* 48, 11–64.

Charette 1999a = —, Der geflügelte Quadrant: ein ungewöhnliches Sinusinstrument aus dem 14. Jh.”, in *Der Weg der Wahrheit. Aufsätze zur Einheit der Wissenschaftsgeschichte*, ed. P. Eisenhardt, F. Linhard and K. Petanides (Hildesheim: Olms), pp. 25-36.

Charette 1999b = —, “Die Bibliothek des Muṣṭafā Ṣidqī ibn Ṣāliḥ (gest. 1769). Die Bedeutung der Handschriftenkunde für die Erforschung der neuzeitlichen osmanischen Wissenschaftsgeschichte”, paper presented at the annual congress of the German Middle East Studies Association (DAVO) in Hamburg, December 2-4.

Charette, “Greenwich Astrolabes” = —, Chapter “Islamic Astrolabes” in *Astrolabes at Greenwich. A Catalogue of the Planispheric Astrolabes in the National Maritime Museum* ed. K. van Cleempoel (to be published by Oxford University Press and the National Maritime Museum, 2003).

Charette & Schmidl 2001 = François Charette and Petra Schmidl, “A Universal Plate for Timekeeping by the Stars by Ḥabash al-Ḥāsib: Text, Translation and Preliminary Commentary”, *Suhayl* (Barcelona) 2, 107–159.

Charette & Schmidl, “Khwārizmī” = —, “al-Khwārizmī and Astronomical Instrumentation in Ninth-Century Baghdad. The Earliest Extant Corpus of Texts in Arabic on the Astrolabe and Other Portable Instruments” (forthcoming).

Cheikho 1913 = Louis Cheikho, “Kitāb al-ʿAmal bi-l-asṭurlāb li-ʿAlī ibn ʿĪsā”, *al-Mashriq* (Beirut) 16, 29–46; repr. in Sezgin, *AIOS*.

Combe 1930 = Étienne Combe, “Cinq cuivres musulmans datés des XIIIe, XIVe

et XVe siècles, de la collection Benaki", *Bulletin de l'Institut Français d'Archéologie Orientale* (Cairo) 30, 49–58; repr. in Sezgin, *AIOS*.

Debarnot 1985 = Marie-Thérèse Debarnot, *Al-Bīrūnī.* Kitāb Maqālīd ʿilm al-hayʾa – *La trigonométrie sphérique chez les Arabes de l'Est à la fin du X^e^ siècle* (Damascus: Institut Français de Damas).

Delambre 1817 = J. B. J. Delambre, *Histoire de l'Astronomie Ancienne*, 2 vols. (Paris; repr. New York: Johnson Reprint, 1965).

Delambre 1819 = —, *Histoire de l'Astronomie du Moyen Age* (Paris; repr. New York: Johnson Reprint, 1965).

De Slane, *Catalogue* = MacGuckin de Slane, *Catalogue des manuscrits arabes de la Bibliothèque nationale* (Paris, 1883).

Dorn 1865 = "Drei in der Kaiserlichen Öffentlichen Bibliothek zu St. Petersburg befindliche astronomische Instrumente mit arabischen Inschriften", *Mémoires de l'Académie Impériale des sciences de St. Pétersbourg*, 7e série, 9, 150 pages; repr. in Sezgin, *AIOS*.

Dozy, *Supplément* = Reinhart P. A. Dozy, *Supplément aux dictionnaires arabes*, 2 vols. (Leiden: Brill, 1881; 2nd ed. 1927; 3rd ed. 1967).

Drachmann 1954 = H. G. Drachmann, "The Plane Astrolabe and the Anaphoric Clock", *Centaurus* 3, 183–189.

Drecker 1925 = Josef Drecker, *Theorie der Sonnenuhren* (Berlin, Leipzig) [= Bassermann-Jordan, ed., *Die Geschichte der Zeitmessung und der Uhren*, Bd I, Lfg E].

Drecker 1931 = —, "Hermannus Contractus: Über das Astrolab", *Isis* 16, 200–219.

DSB = *Dictionary of Scientific Biography*, ed. C. C. Gillispie, 16 vols. (New York: Scribner's, 1970–1980).

EI^2 = *The Encyclopedia of Islam*, new ed. (Leiden: Brill, 1960–)

Europa und der Orient = *Europa und der Orient, 800–1900*, [exhibition catalogue, Festival der Weltkulturen Horizonte 89, Berlin, May 28–August 27, 1989], ed. G. Sievernich and H. Budde (Munich: Bertelsmann-Lexikon-Verlag, 1989).

Féhérvári 1973 = G. Féhérvári, "A VIIIth/XIVth century quadrant of the astrolabist al-Mizzi", *Bulletin of the School of Oriental and African Studies* 36, 115–117 and two plates.

Focus Behaim Globus = Germanisches Nationalmuseum, *Focus Behaim Globus. Nürberg, 2. Dezember 1992–28. Februar 1993*, 2 vols. [Teil 1: Aufsätze. Teil 2: Katalog] (Nuremberg, 1992).

Folkerts & Lorch 2000 = *Sic Itur ad Astra. Studien zur Geschichte der Mathematik und Naturwissenschaften. Festschrift für den Arabisten Paul Kunitzsch zum 70. Geburtstag*, ed. M. Folkerts and R. Lorch (Wiesbaden: Verlag Otto Harrassowitz).

Frank 1920 = Josef Frank, *Zur Geschichte des Astrolabs* (Erlangen: Universitäts-Buchdruckerei von Junge und Sohn); repr. in Sezgin, *AIOS*.

Frank 1921 = —, "Über zwei astronomische arabische Instrumente", *Zeitschrift für Instrumentenkunde* 40/7, 193–200; repr. in Sezgin, *AIOS*.

See also Wiedemann and Frank.

Garbers 1936 = Karl Garbers, "Ein Werk Ṯābit b. Qurra's über ebene Sonnenuhren", *Quellen und Studien zur Geschichte der Mathematik, Astronomie und Physik*, Abteilung A, 4.

Gibbs 1976 = Sharon Gibbs, *Greek and Roman sundials* (New Haven and London: Yale University Press).

Glasemann 1999 = Reinhard Glasemann, *Erde, Sonne, Mond & Sterne. Globen, Sonnenuhren und astronomische Instrumente im Historischen Museum Frankfurt am Main* (Frankfurt, Verlag Waldemar Kramer) [Schriften des Historischen Museum Frankfurt am Main, Band 20].

Goldstein 1987 = Bernard Goldstein, "Description of astronomical instruments in Hebrew", in King and Saliba 1987, pp. 105–141.

Gounaris 1980 = G. Gounaris, "Anneau astronomique solaire portatif antique découvert à Philippe", *Annali dell' Istituto e Museo di Storia della Scienza di Firenze* 5, 3–18.

Grant 1994 = Edward Grant, *Planets, Stars, & Orbs. The Medieval Cosmos, 1200–1687* (Cambridge: Cambridge University Press).

Gunther 1923 = Robert T. Gunther, *Early Science in Oxford* (Oxford).

Gunther 1932 = —, *The Astrolabes of the World* (Oxford).

Ḥājjī Khalīfa, *Kashf al-ẓunūn* = Muṣṭafā ibn ʿAbd Allāh Ḥājjī Khalīfa [d. 1657], *Kashf al-ẓunūn ʿan asāmī 'l-kutub wa-l-funūn*, ed. Ş. Yaltkaya and K. R. Bilge (Istanbul, 1941–43).

Hankins 1999 = Thomas L. Hankins, "Blood, Dirt, and Nomograms. A Particular History of Graphs", *Isis* 90, 50–80.

Hankins & Silverman 1995 = T. Hankins and Robert J. Silverman, *Instruments and the Imagination* (Princeton: Princeton University Press).

Hartner 1938-39 = W. Hartner, "The principle and use of the astrolabe", in Arthur Upham Pope, *A Survey of Persian Art*, 6 vols. (Oxford); repr. in Hartner, *Oriens-Occidens* (Hildesheim, 1984), II, pp. 287–311.

Heath 1956 = Thomas L. Heath, *Euclid: The Thirteen Books of The Elements*, 2nd ed., 3 vols. (New York: Dover).

Hill 1974 = Donald Hill, *The Book of Knowledge of Ingenious Mechanical Devices by Ibn al-Razzāz al-Jazarī* (Dordrecht: Reidel).

Hill 1979 = —, *The Book of Ingenious Devices by the Banū Mūsā ibn Shākir* (Dordrecht: Reidel).

Hill 1985 = —, "al-Bīrūnī's Mechanical Calendar", *Annals of Science* 42, 139–163; repr. in idem 1988, item XIV.

Hill 1998 = —, *Studies in Medieval Islamic Technology* (Aldershot: Ashgate/Variorum).

Hogendijk 1986 = Jan Pieter Hogendijk, "Discovery of an 11th-Century Geometrical Compilation: The *Istikmāl* of Yūsuf al-Muʾtaman ibn Hūd", *Historia Mathematica* 13, 43–52.

Hogendijk 1991 = —, "The Geometrical Parts of the *Istikmāl* of Yūsuf al-Muʾtaman ibn Hūd (11th century)", *Archives Internationales d'Histoire des Sciences* 41, 207–281.

Hogendijk 1996 = —, *Al-Sijzī's Treatise on Geometrical Problem Solving* (Tehran: Fatemi Publishing).

Hogendijk 2001 = —, "The Contributions by Abū Naṣr ibn ʿIrāq and al-Ṣaghānī to the Theory of Seasonal Hour Lines on Astrolabes and Sundials", *Zeitschrift für Geschichte der arabisch-islamischen Wissenschaften* 14, 1–30.

Hopwood 1963 = D. Hopwood, H. L. Gottschalk, J. S. Trimingham and A. F. L. Beeston, *A Catalogue of the Mingana Collection of Manuscripts* (Birmingham), Vol IV: Islamic Arabic Manuscripts (Birmingham: The Selly Oak Colleges Library).

Ibn al-Akfānī = Jan Just Witkam, *De egyptische arts Ibn al-Akfānī (gest. 749/1348) en zijn indeling van den wetenschappen* (Leiden: Ter Lugt Pers, 1989).

Ibn Ḥajar, *Durar* = Ibn Ḥajar al-ʿAsqalānī [d. 1449], *Durar al-kāmina fī aʿyan al-miʾa al-thāmina* 5 vols. (Cairo: Dār al-Kutub al-Ḥadītha, [1966–1967]).

Ibn al-Nadīm, *Fihrist* = Muḥammad ibn Isḥāq ibn al-Nadīm [d. 995], *Fihrist*, ed. Rida Tajaddud (Tehran, 1971).

Ibn Sīnā, *Shifāʾ* = Abū ʿAlī ibn Sīnā [d. 1037], *al-Shifāʾ*. The two volumes consulted are: *al-Riyāḍiyyāt, 4: ʿIlm al-hayʾa*, ed. I. Madkur *et al.* (Cairo, 1980). *al-Ṭabīʿiyyāt, 2: al-samāʾ wa-l-ʿālam*, ed. I. Madkur *et al.* (Cairo, 1965).

Ibn Taghrībirdī, *Manhal* = Abū al-Maḥāsin Yūsuf Ibn Taghrībirdī [d. 1470], *al-Manhal al-Ṣāfī wa-l-mustawfā baʿda al-wāfī*, ed. A. Y. Najātī, 8 vols. (Cairo, 1956).

Ibrāhīm ibn Sinān 1948 = *Rasāʾil ibn Sinān* (Hyderabad, 1367 H [= 1948]).

Ibrāhīm ibn Sinān 1983 = *Rasāʾil ibn Sinān*, ed. Aḥmad Salīm Saʿīdān (Kuwayt).

See also Bellosta & Rashed 2000 and Luckey & Hogendijk 1941/1999.

Ihsanoğlu, *OALT* = *Osmanlı Astronomi Literatürü Tarihi*, ed. E. Ihsanoğlu *et al.*, 2 vols. (Istanbul: IRCICA, 1998).

Janin 1972 = Louis Janin, "Le cadran solaire de la Mosquée Umayyade à Damas", *Centaurus* 16, 285–298.

Janin 1979 = —, "Astrolabe et cadran solaire en projection horizontale", *Centaurus* 22, 298–314.

Janin & King 1977 = L. Janin and D. A. King, "Ibn al-Shāṭir's *Ṣandūq al-yawāqīt*: An Astronomical 'Compendium' ", *Journal for the History of Arabic Science* 1, 187–256; repr. in King 1987a, item XII.

Janin & King 1978 = —, "Le cadran solaire de la mosquée d'Ibn Ṭulūn au Caire", *Journal for the History of Arabic Science* 2, 331–357; repr. in King 1987a, item XVI.

Janin & Rohr 1975 = L. Janin and R. Rohr, "Deux astrolabes-quadrants turcs", *Centaurus* 19, 108–124.

Karatay 1966 = F. E. Karatay, *Topkapı Sarayı Müzesi Kütüphanesi arapça yazmalar kataloğu*, Volume CIII: Akaid, Tasavvuf, Mecalis, Ediye, Tarih, Siyer, Teracim, Bilimler (Istanbul).

Kennedy & Ghanem 1976 = E. S. Kennedy and Imad Ghanem (eds), *The Life and Works of Ibn al-Shāṭir. An Arab Astronomer of the Fourteenth Century* (Aleppo).

Kennedy, Kunitzsch & Lorch 1999 = E. S. Kennedy, P. Kunitzsch and R. Lorch, *The Melon-Shaped Astrolabe in Arabic Astronomy. Texts edited with translation and commentary* (Stuttgart: Steiner).

al-Khwārizmī, *Mafātīḥ al-ʿulūm* = Abū ʿAbdallāh Muḥammad ibn Aḥmad ibn Yūsuf al-Khwārizmī al-Kātib, *Kitāb Mafātīḥ al-ʿulūm*, ed. G. van Vloten (Leiden: Brill, 1895; repr. 1968).

King 1972 = David A. King, *The Astronomical Works of Ibn Yūnus*, Ph.D. dissertation, Yale University.

King 1973a = —, "Ibn Yūnus' *Very Useful Tables* for Reckoning Time by the Sun", *Archive for History of Exact Sciences* 10, 342–394; repr. in King 1986, IX.

King 1973b = —, "Al-Khalīlī's Auxiliary Tables for Solving Problems of Spherical Astronomy", *Journal for the History of Astronomy* 4, 99–110; repr. in King 1986, XI.

King 1974 = —, "An Analog Computer for Solving Problems of Spherical Astronomy: The *Shakkāzīya* Quadrant of Jamāl al-Dīn al-Māridīnī", *Archives Internationales d'Histoire des Sciences* 24, 219–242; repr. in King 1987a, item X.

King 1975a = —, "The Astronomical Tables of the Islamic Middle Ages", *Studia Copernicana* 13, Wrocław, pp. 37–56; repr. in King 1986, II.

King 1975b = —, "Al-Khalīlī's Qibla Table", *Journal of Near Eastern Studies* 34, 81–122; repr. in King 1986, XIII.

King 1976 = —, "Astronomical Timekeeping in Fourteenth-Century Syria", *Proceedings of the First International Symposium for the History of Arabic Science, Aleppo*, Aleppo, 1978, vol. II, pp. 75–84; repr. in King 1986, X.

King 1977 = —, "Astronomical Timekeeping in Ottoman Turkey", *Proceedings of the International Symposium on the Observatories in Islam*, Istanbul, pp. 245–269; repr. in King 1986, XII.

King 1978a = —, "Three sundials from Islamic Andalusia", *Journal for the History of Arabic Science* 2, 358–392; repr. in King 1987a, item XV.

King 1978b = —, "A Note on the Astrolabist Nasṭūlus/Basṭūlus", *Archives Internationales d'Histoire des Sciences* 28, 117–120; repr. in King 1987a, item IV.

King 1979a = –, "On the Early History of the Universal Astrolabe in Islamic Astronomy and the Origin of the Term 'shakkāzīya' in Medieval Scientific Arabic", *Journal for the History of Arabic Science* 3, 244–257; repr. in King 1987a, item VII.

King 1979b = —, "Notes on the Sources for the History of Early Islamic Mathematics" [Essay review of Sezgin, *GAS*, V], *JAOS* 99/3, 450–459.

King 1983a = —, "The Astronomy of the Mamluks", *Isis* 74, 531–555; repr. in King 1986, III.

King 1983b = —, "al-Khwārizmī and New Trends in Mathematical Astronomy in the Ninth Century", *Occasional Papers on the Near East*, The Hagop Kevorkian Center for Near Eastern Studies, New York University, Number 2.

King 1983c = —, *Mathematical Astronomy in Medieval Yemen: A Bio-bibliographical Survey* (Malibu CA: Undena).

King 1984 = —, "Architecture and Astronomy: the Ventilators of Medieval Cairo and Their Secrets", *Journal of the American Oriental Society*, 104, 97–133; repr. in idem, *SATMI*, IXb.

King 1986 = —, *Islamic Mathematical Astronomy* (London: Variorum Reprints; 2nd ed. 1993).

King 1987a = —, *Islamic Astronomical Instruments* (London: Variorum Reprints; repr. 1995).

King 1987b = —, "Universal Solutions in Islamic Astronomy", in Berggren and Goldstein 1987; repr. in King 1993a, item VI; repr. in idem, *SATMI*, VIa.

King 1987c = —, "The Astronomical Instruments of Ibn al-Sarrāj", in King 1987a, item IX, 3 pages [revised version of a paper presented at the Second International Symposium for the History of Arabic Science, Aleppo, 1979].

King 1988 = —, "Universal Solutions to Problems of Spherical Astronomy from Mamluk Egypt and Syria", in *A Way Prepared: Essays on Islamic Culture in Honor of Richard Bayly Winder*, ed. F. Kazemi and R. D. McChesney (New York: New York University Press); repr. in King 1993a, item VII; also repr. in idem, *SATMI*, VIb.

King 1990 = —, "Mīqāt: Astronomical Timekeeping", in *EI*^{2}, VII, pp. 27–32; repr. in King 1993a, item V.

King 1991 = —, "Strumentazione astronomica nel mondo islamico", in G. Turner 1991, pp. 154–189.

King 1992 = —, "Los cuadrantes solares andalusíes", in Samsó 1992, pp. 89–102.

King 1993a = —, *Astronomy in the Service of Islam* (Aldershot: Ashgate/Variorum).

King 1993b = —, "L'astronomie en Syrie à l'époque islamique", in *Syrie, mémoire et civilisation*, ed. J. Mouliérac (Paris: Institut du monde arabe), pp. 386–395 [essay] and pp. 432–443 [catalogue entries].

King 1993c = —, "Some Medieval Astronomical Instruments and Their Secrets", in *Non-Verbal Communication in Science Prior to 1900*, ed. R. G. Mazzolini (Florence: Olschki), pp. 29–52.

King 1993d = —, "Folk Astronomy in the Service of Religion: the Case of Islam", in *Astronomies and Cultures* ed. C. Ruggles and N. Saunders (Niwot CO: University Press of Colorado).

King 1995 = —, "Early Islamic Astronomical Instruments in Kuwaiti Collections", in *Kuwait – Arts and Architecture. A Collection of Essays*, ed. A. Fullerton and G. Fehérvári (Kuwait), pp. 76–96.

King 1996a = —, "On the Role of the Muezzin and the *Muwaqqit* in Medieval Islamic Society", in *Tradition, Transmission, Transformation: Proceedings of Two Conferences on Premodern Science Held at the University of Oklahoma*, ed. F. J. Ragep, S. P. Ragep and S. Livesey (Leiden: Brill), pp. 285–346.

King 1996b = —, "Astronomy and Islamic Society: Qibla, gnomonics and timekeeping", in *Encyclopedia of the History of Arabic Science*, ed. R. Rashed, 3 vols. (London: Routledge), I, pp. 128–184.

King 1996c = —, "The Neglected Astrolabe", in *Mathematische Probleme im Mittelalter — Der lateinische und arabische Sprachbereich* ed. M. Folkerts (Wiesbaden: Harrassowitz), pp. 45–55.

King 1999 = —, *World-Maps for Finding the Direction and Distance to Mecca – Innovation and Tradition in Islamic Science* (Leiden: Brill).

King 2001 = —, *The Ciphers of the Monks. A Forgotten Numeral Notation of the Middle Ages* (Stuttgart: Steiner).

King 2002 = —, "A *Vetustissimus* Arabic Treatise on the *Quadrans Vetus*", *Journal for the History of Astronomy* 33, 237–255.

King, *Fihris* = —, *Fihris al-makhṭūṭāt al-ʿilmiyya al-ʿarabiyya fī Dār al-Kutub al-Miṣriyya*, 2 vols. (Cairo, 1981–1982).

King, *Survey* = —, *A Survey of the Scientific Manuscripts in the Egyptian National Library* (Winona Lake, IN: Eisenbrauns, 1986).

King, *SATMI* = —, *Studies in Astronomical Timekeeping in Medieval Islam* (Leiden: Brill, to appear). [Part I: A Survey of Tables for Timekeeping by the Sun and Stars. Part II: A Survey of Tables for Regulating the Times of Prayer. Part III: A

Survey of Arithmetical Shadow-Schemes for Time-Reckoning. Part IV: On the Times of Prayer in Islam. Part V: On the Role of the Muezzin and the Muwaqqit in Medieval Islamic Society. Part VIa: Universal Solutions in Medieval Islamic Astronomy Part VIb: Universal Solutions from Mamluk Syria and Egypt. Part VIIa: An Approximate Formula for Timekeeping (750-1900). Part VIIb: On The Universal Horary Quadrant for Timekeeping by the Sun. Part VIII: Astronomical Instrumentation in the Medieval Islamic World. Part IXa: On the Orientation of Medieval Islamic Architecture and Cities. Part IXb: Architecture and Astronomy: The Ventilators of Medieval Cairo and their Secrets. Part IXc: Safavid World-Maps Centred on Mecca. Part X: Aspects of Applied Science in Mosques and Monasteries.]

King, "Universal Horary Dials" = —, "On Universal Horary Dials for Timekeeping by the Sun and Stars", to appear in *Centaurus* (special issue in honour of Bernard Goldstein).

King, *Frankfurt Catalogue* = —, *A Catalogue of Medieval Astronomical Instruments*, unpublished. [A preliminary table of contents is available in the internet under: http://www.uni-frankfurt.de/fb13/ign/instrument-catalogue.html.]

King & Saliba 1987 = *From Deferent to Equant: A Volume of Studies in the History of Science in the Ancient and Medieval Near East in Honor of E. S. Kennedy*, ed. D. King and G. Saliba (New York).

King & Samsó 2001 = D. King and J. Samsó (with B. Goldstein), "Astronomical Handbooks and Tables from the Islamic World (750-1900): an Interim Report", *Suhayl* (Barcelona) 2, 9–105.

King & Turner 1994 = D. King and G. Turner, "The Astrolabe Presented by Regiomontanus to Cardinal Bessarion in 1462", *Nuncius. Annali di Storia della Scienza* (Florence) 9, 165–206.

King & Walls 1979 = D. King and A. G. Walls, "The Sundial on the West Wall of the Madrasa of Sultan Qaytbay in Jerusalem", *Art and Architecture Reseach Papers* 15, 16–21; repr. in King 1987a, item XVII.

King & Charette, "Astrolabe tables" = D. King and F. Charette, "A Survey of Medieval Islamic Tables for Constructing Astrolabes" (forthcoming).

King & Charette, *Universal Astrolabe* = *The Universal Astrolabe of Ibn al-Sarrāj* (forthcoming).

Krause 1936 = Max Krause, "Stambuler Handschriften islamischer Mathematiker", *Quellen und Studien zur Geschichte der Mathematik un Physik*, Abteilung B, 3, 437–532.

Kren 1977 = Claudia Kren, "The Traveller's Dial in the Middle Ages: the Chilinder", *Technology and Culture* 18, 419–435.

Kunitzsch 1959 = Paul Kunitzsch, *Arabische Sternnamen in Europa* (Wiesbaden: Otto Harrassowitz).

Kunitzsch 1980 = —, "Two Star Tables from Muslim Spain", *Journal for the History of Astronomy* 11, 192–201.

Kunitzsch 1981 = —, "Observations on the Arabic Reception of the Astrolabe", *Archives Internationales d'Histoire des Sciences* 31, 243–252.

Kunitzsch 1982 = —, *Glossar der arabischen Fachausdrücke in der mittelalterlichen europäischen Astrolabliteratur* (Göttingen: Vandenkoeck & Ruprecht, 1983) [=

Nachrichten der Akademie der Wissenschaften in Göttingen. I. Philologisch-Historische Klasse, Jahrgang 1982, Nr. 11, pp. 455-571].

Kunitzsch 1984 = —, “Remarks Regarding the Terminology of the Astrolabe”, *Zeitschrift für Geschichte der arabisch-islamischen Wissenschaften* 1, 55–60.

Kunitzsch 1986-91 = —, *Claudius Ptolemäus: Der Sternkatalog des Almagest. Die arabisch-lateinische Tradition*, 3 vols. (Wiesbaden: Harrassowitz).

Kunitzsch 1990 = —, “al-Ṣūfī and the Astrolabe Stars”, *Zeitschrift für Geschichte der arabisch-islamischen Wissenschaften* 6, 151–166.

Kunitzsch & Lorch 1994 = P. Kunitzsch and R. Lorch, *Maslama’s Notes on Ptolemy’s Planisphærium and Related Texts* (Munich) [= Sitzungsberichte der Bayerischen Akademie der Wissenschaften, Philologisch-Historische Klasse, Jahrgang 1994, Heft 2].

Lane, *English-Arabic Lexicon* = Edward William Lane, *An English-Arabic Lexicon*, 8 vols. (London, 1885; repr. Beirut: Librairie du Liban, 1968).

Lelewel 1850-57 = Joachim Lelewel, *Géographie du moyen-âge*, 5 vols. and an atlas (Bruxelles).

Livingston 1972 = John Livingston, “The Mukḥula, an Islamic Conical Sundial”, *Centaurus* 16, 299–308.

Löfgren & Traini 1975 = Oscar Löfgren and Renato Traini, *Catalogue of the Arabic Manuscripts in the Bibliotheca Ambrosiana* (Vincenza: Pozza).

Lorch 1980 = Richard Lorch, “The *sphera solida* and Related Instruments” *Centaurus* 24, 153–161, repr. in Lorch 1995 as item XII.

Lorch 1981 = —, “A Note on the Horary Quadrant”, *Journal for the History of Arabic Science* 5, 115–120.

Lorch 1994 = —, “Mischastrolabien im arabisch-islamischen Kulturgebiet”, in *Ad radices. Festband zum fünfzigjährigen Bestehen des Instituts für Geschichte der Naturwissenschaften der Johann Wolfgang Goethe-Universität, Frankfurt am Main*, ed. A. von Gotstedter (Stuttgart: Steiner), pp. 231–236.

Lorch 1995 = —, *Arabic Mathematical Sciences – Instruments, Texts, Transmission* (Aldershot: Ashgate/Variorum).

Lorch 1996 = —, “Ptolemy and Maslama on the Transformation of Circles into Circles in Stereographic Projection”, *Archive for History of Exact Sciences*, 49 (1995-96), 271–284.

Lorch 2000a = —, “Some Early Applications of the Sine Quadrant”, *Suhayl* (Barcelona) 1, 251–272.

Lorch 2000b = —, “Ibn al-Ṣalāḥ’s Treatise on Projection: a Preliminary Survey”, in Folkerts & Lorch 2000, pp. 401–408.

Luckey 1937-38 = Paul Luckey, “Ṯābit b. Qurra’s Buch über die ebenen Sonnenuhren”, *Quellen und Studien zur Geschichte der Mathematik, Astronomie und Physik*, Abteilung B, 4, 95–148.

Luckey & Hogendijk 1941/1999 = *Die Schrift des Ibrāhīm b. Sinān b. Ṯābit über die Schatteninstrumente*, übersetzt und erläutert von Paul Luckey (Phil. Diss. Tübingen, 1941), herausgegeben von Jan P. Hogendijk (Frankfurt: Institut für Geschichte der Arabisch-Islamischen Wissenschaften, 1999).

Maddison 1962 = Francis R. Maddison, “A fifteenth-century Islamic spherical astrolabe”, *Physis* 4, 101–109.

Maddison 1966 = —, “Hugo Helt and the Rojas’ Astrolabe Projection”, in *Agrupamento de Estudos de Cartografia Antiga XII* (Coimbra).

Maddison & Savage-Smith 1997 = F. Maddison and E. Savage-Smith, *Science, Tools & Magic. Part One. Body and Spirit, Mapping the Universe*, 2 vols. (London and Oxford: Nour Foundation, Azimuth Editions and Oxford University Press) [The Nasser D. Khalili Collection of Islamic Art, Volume XII].

Mancha 1998 = J. L. Mancha, “On Ibn al-Kammād’s Tables for Trepidation”, *Archive for History of Exact Sciences* 52, 1–11.

al-Marrākushī, *Jāmiʿ* = Abū ʿAlī al-Marrākushī, *Jāmiʿ al-mabādiʾ wa-l-ghāyāt fī ʿilm al-mīqāt*, facsimile ed. of MS Istanbul, Topkapı, Ahmet III 3343, ed. by Fuat Sezgin, 2 vols. (Frankfurt: Institut für Geschichte der Arabisch-Islamischen Wissenschaften, 1984).

al-Masʿūdī, *Murūj* = al-Masʿūdī [d. 956], *Murūj al-dhahab wa-maʿdin al-jawhar* [French title: *Les Prairies d’Or*], ed. and transl. C. Barbier de Meynard and A. Pavet de Courteilles, 9 vols. (Paris: Imprimerie Impériale, 1861-1877).

Mayer 1956 = L. A. Mayer, *Islamic astrolabists and their works* (Geneva: Kundig).

Meyer 1980 = Wolfgang Meyer, “Sundials of the Osmanic Era in Istanbul”, in *International Symposium on the Observatories in Islam, 19-23 September 1977*, ed. M. Dizer (Istanbul), pp. 193–203.

Michel 1941 = Henri Michel, “Méthodes de tracé et d’exécution des astrolabes persans”, *Ciel et Terre* 12, 481–496.

Michel 1943 = —, “L’astrolabe linéaire d’al-Tûsi”, *Ciel et Terre* 59, 101–107.

Michel 1966 = —, *Instruments des sciences dans l’art et l’histoire* (Paris: Société française du livre).

Michel 1976 = —, *Traité de l’astrolabe* (2nd rev. ed., Paris).

Michel 1977 = —, *Images des sciences. Les anciens instruments scientifiques vus par les artistes de leur temps* (Rhode-St-Genèse (Belgium): Albert de Visscher).

Michot 2000 = Y. J. Michot, “Ibn Taymiyya on Astrology. Annotated Translation of Three Fatwas”, *Journal of Islamic Studies* 11, 147–208.

Millás 1932 = José Maria Millás-Vallicrosa, “La introducción del cuadrante con cursor en Europa”, *Isis* 17, 218–258.

Millás 1933 = —, *Don Profeit Tibbon. Tractat de l’Assafea d’Azarquiel* (Barcelona).

Millás 1943-50 = —, *Estudios sobre Azarquiel* (Madrid and Granada, 1943-50).

Mills 1996 = “Altitude Sundials for Seasonal and Equal Hours”, *Annals of Science* 53, 75–84.

Morelon 1984 = Régis Morelon, *Thābit ibn Qurra. Œuvres d’Astronomie* (Paris: Belles-Lettres).

Moreno, Van Cleempoel & King 2002 = Roberto Moreno, Koenraad Van Cleempoel and David King, “A Recently Discovered Sixteenth-Century Spanish Astrolabe”, *Annals of Science* 59, 331–362.

Morley 1856 = William H. Morley, *Description of a Planispheric Astrolabe, Constructed for Sháh Sultán Husain Safawí, King of Persia, and now Preserved in the British Museum* (London); repr. in Sezgin, *AIOS*.

Morley 1860 = —, “Description of an Arabic Quadrant”, *Journal of the Royal Asiatic Society of Great Britain and Ireland* 17, 322–330; repr. in Sezgin, *AIOS*.

Mortillaro 1848 = V. Mortillaro, "Illustrazione di un astrolabio arabo del nono secolo", in idem, *Opere*, vol. 4, Palermo, pp. 110–135; repr. in Sezgin, *AIOS*.

Mouliérac 1989 = Jeanne Mouliérac, "La collection Marcel Destombes", in A. Turner 1989, pp. 77–126.

Naffah 1989 = Christiane Naffah, "Un cadran cylindrique ottoman du XVIII$^{\text{ème}}$ siècle", in in A. Turner 1989, pp. 37–51.

Nasr 1976 = Seyyed Hossein Nasr, *Islamic Science. An Illustrated Study* (London: World of Islam Publishing Cie).

Nasr 1978 = —, *An Introduction to Islamic Cosmological Doctrines* rev. ed. (Boulder, CO: Shambala Publications).

Neugebauer 1949 = Otto Neugebauer, "The Early History of the Astrolabe", Isis 40, 240–256.

Neugebauer 1975 = —, *A History of Ancient Mathematical Astronomy*, 3 vols. (New York and Berlin: Springer).

Nolte 1922 = Friedrich Nolte, *Die Armillarsphäre* (Erlangen) [Abhandlungen zur Geschichte der Naturwissenschaften und der Medizin, Heft 2].

North 1966-67 = John North, "Werner, Apian, Blagrave and the Meteoroscope", *British Journal of the History of Science* 3, 57–65.

North 1974 = —, "The Astrolabe", *Scientific American* 230, 96–106.

North 1976 = —, *Richard of Wallingford. An Edition of His Writings with Introductions, English Translations and Commentary*, 3 vols. (Oxford).

North 1981 = —, "Astrolabes and the Hour-line Ritual", *Journal for the History of Arabic Science* 5, 113–114.

North 1987 = —, "Coordinates and Categories: the Graphical Representation of Functions in Medieval Astronomy", in *Mathematics and Its Applications. Studies Presented to Marshall Clagett*, ed. E. Grant and J. Murdoch (Cambridge), pp. 173–188; repr. in North, *The Universal Frame. Historical Essays in Astronomy, Natural Philosophy and Scientific Method* (London: Hambledon Press, 1989).

d'Ocagne 1899 = Maurice d'Ocagne, *Traité de nomographie: Théorie des abaques, applications pratiques* (Paris: Gauthier-Villars).

Pingree 1970 = David Pingree, "The Fragments of the Works of al-Fazārī", *Journal of Near Eastern Studies* 29, 102–123.

Poulle 1970 = Emmanuel Poulle, "Un astrolabe astronomique dans l'Occident latin: la 'saphea' " in *A Giuseppe Ermini* (Spoleto: Centro Italiano di Studi Sull' Alto Medioevo), pp. 491–510.

Poulle 1983 = —, *Les instruments astronomiques du moyen-âge* (Paris: Société Internationale de l'Astrolabe) [Astrolabica, 3].

Price 1969 = Derek de Solla Price, "Portable Sundials in Antiquity, including an Account of a New Example from Aphrodisias", *Centaurus* 14, 242–266.

Ptolemy, *Almagest* = *Ptolemy's Almagest*, translated and annotated by G. J. Toomer (London: Duckworth, 1984; Princeton: Princeton University Press, 1998).

Ptolemy, *Syntaxis Mathematica* = *Claudii Ptolemaei opera quae exstant omnia. I: Syntaxis Mathematica* (Leipzig: Teubner, 1898).

Puig 1985 = Roser Puig, "Concerning the ṣafīḥa shakkāziyya", *Zeitschrift für Geschichte der arabisch-islamischen Wissenschaften* 2, 123–139.

Puig 1986 = —, *Al-Šakkāziyya. Ibn al-Naqqāš al-Zarqālluh. Edición, traducción y estudio* (Barcelona: Universidad de Barcelona, Instituto "Millás Vallicrosa" de Historia de la Ciencia Árabe).

Puig 1987a = —, *Los tratados de construcción y uso de la azafea de Azarquiel* (Madrid: Instituto Hispano-Árabe de Cultura).

Puig 1987b = —, "La proyección ortográfica en el *Llibro de la Açafeha* alfonsi", in *De Astronomia Alfonsi Regis*, ed. M. Comes, R. Puig and J. Samsó (Barcelona).

Puig 1987c = —, "El *taqbīl ʿala risālat al-safīha al-zarqāliyya* de Ibn al-Bannā' de Marrākush", *Al-Qantara* 8, 45–64.

Puig 1989 = —, "Al-Zarqālluh's Graphical Method for Finding Lunar Distances", *Centaurus* 32, 294–309.

Puig 1992 = —, "Intrumentos universales en al-Andalus", in *El legado científico Andalusí* (Madrid: Ministerio di Cultura), pp. 67–73.

Puig 1996 = —, "On the Eastern Sources of Ibn al-Zarqālluh's Orthographic Projection", in Casulleras and Samsó 1996, II, pp. 737–753.

Quatremère, *Mamlouks* = Etienne Quatremère, *Histoire des Sultans Mamlouks*, 2 vols. (Paris, 1837-45).

Ragep 1993 = F. Jamil Ragep, *Naṣīr al-Dīn al-Ṭūsī's* Memoir on Astronomy, 2 vols. (New York: Springer).

Rashed 1986 = Roshdi Rashed, *Sharaf al-Dīn al-Ṭūsī. Oeuvres mathématiques*, 2 vols. (Paris: Belles-Lettres).

Reich & Wiet 1939-40 = S. Reich and G. Wiet, "Un astrolabe syrien du XIVe siècle", *Bulletin de l'Institut Français D'Archéologie Orientale* (Cairo) 38-39, 195–202; repr. in Kennedy & Ghanem 1976, pp. 36–43.

Richard 2000 = Francis Richard, "Les « portraits » de Naṣīr al-Dīn Ṭūsī", in *Naṣīr al-Dīn Ṭūsī, philosophe et savant du XIII^e^ siècle* (Téhéran: Institut Français de Recherches en Iran & Presses Universitaires d'Iran).

Rico y Sinobas 1863–66 = Manuel Rico y Sinobas (ed.), *Libros del saber de astronomía del Rey D. Alfonso X de Castilla*, 5 vols. (Madrid).

Rohr 1974 = René R. Rohr, "Astrolabium und Sonnenuhr im Dienste der Moschee", *Centaurus* 18, 44–56.

Rohr 1986 = —, *Les cadrans solaires. Histoire, théorie, pratique*, éd. revue et augmentée (Strasbourg: Odelin).

Rozenfeld 1983 = Boris Rosenfeld *et al.*, *Muhammad ibn Musa al-Khorezmi* (Moscow: Nauka) [in Russian].

Rosenthal 1950 = Franz Rosenthal, "Al-Asṭurlâbî and as-Samaw'al on Scientific Progress", *Osiris* 9, pp. 555–564.

Ruska 1920 = J. Ruska, "Arabische Texte über das Fingerrechnen", *Der Islam* 10, 87–119.

Sabra 1987 = Abd al-Hamid Ibrahim Sabra, "The Appropriation and Subsequent Naturalization of Greek Science in Medieval Islam: A Preliminary Statement", *History of Science* 25, 223–243.

al-Ṣafadī, *Nakt* = Khalīl ibn Aybak al-Ṣafadī [d. 1363], *Nakt al-himyān fī nukat al-ʿumyān*, ed. Ṭāriq al-Ṭanṭāwī (Cairo: Dār al-Ṭalāʾiʿ, [1997]).

al-Sakhāwī, *Ḍaw*ʾ = Shams al-Dīn Muḥammad al-Sakhāwī [d. 1497], *al-Ḍaw*ʾ *al-lāmi*ʿ *fī aʿyān al-qarn al-tāsi*ʿ, 12 vols. (Cairo 1353–55 [= 1934–36]).

Saliba 1982 = George Saliba, "The Development of Astronomy in Medieval Islamic Society", *Arab Studies Quarterly* 4, 211-225; repr. in Saliba 1994, pp. 51–65.

Saliba 1992 = —, "The Role of the Astrologer in Medieval Islamic Society", *Bulletin d'Etudes Orientales* 44, 45–67 and 6 plates.

Saliba 1994 = —, *A History of Islamic Astronomy. Planetary Theories during the Golden Age of Islam* (New York and London: New York Universtiy Press).

Samsó 1966 = Julio Samsó, "Nota acerca de cinco manuscritos sobre astrolabio", *Al-Andalus*, 31, 385–392.

Samsó 1969 = —, *Estudios sobre Abū Naṣr Manṣūr b. ʿAlī b. ʿIrāq* (Barcelona: Asociación para la historia de la ciencia española).

Samsó 1971 = —, "Una hipótesis sobre cálculo por aproximación con el cuadrante shakkāzī", *Al-Andalus* 36, 117–126.

Samsó 1972 = —, "À propos de quelques manuscrits astronomiques des bibliothèques de Tunis: contribution à une étude de l'astrolabe dans l'Espagne musulmane", in *Actas del II Coloquio Hipano-Tunecino* (Madrid and Barcelona), pp. 171–190.

Samsó 1980 = —, "Maslama al-Majrīṭī and the Alphonsine Book on the Construction of the Astrolabe", *Journal for the History of Arabic Science* 4, 3–8.

Samsó 1987 = —, "Sobre el trazado de la azafea y de lamina universal: intervención de los colaborades alfonsies", *al-Qantara* 8, pp. 29–43; repr. in Samsó 1994, item XV.

Samsó 1992 = *El legado científico Andalusí* ed. J. Samsó *et al.* (Madrid: Ministerio de Cultura).

Samsó 1994 = —, *Islamic Astronomy and Medieval Spain* (Aldershot: Ashgate/Variorum).

Samsó & Catalá 1971 = J. Samsó and M. A. Catalá, "Un instrumente astronómico de raigambre zarqālī: el cuadrante shakkāzī de Ibn Tībughā", *Memoria de la Real Academia de Buenas Letras de Barcelona*, pp. 5–31.

Sarma 1996 = Sreeramullah Rajeswara Sarma, "The *ṣafīḥa zarqālliyya* in India", in Casulleras & Samsó 1996, II, pp. 717–735.

Sauvaire 1894–1896 = Henri Sauvaire, *Description de Damas*, series of articles originally published in the *Journal Asiatique*; repr. in *Islamic Geography*, ed. F. Sezgin, vols. 80–82 (Frankfurt: Institut für Geschichte der Arabisch-Islamischen Wissenschaften, 1993).

Sayılı1960 = Aydın Sayılı, *The Observatory in Islam and its Place in the General History of the Observatory* (Ankara: Türk Tarih Kurumu Basımevi; repr. New York, 1980).

Schaldach 1997 = Karlheinz Schaldach, *Römische Sonnenuhren. Eine Einführung in die antike Gnomonik* (Thun and Frankfurt am Main: Verlag Harri Deutsch).

Schmalzl 1929 = Peter Schmalzl, *Zur Geschichte des Quadranten bei den Arabern*, Inaugural Dissertation, Universität Erlangen (München).

Schoy 1913 = Karl Schoy, "Arabische Gnomonik", *Archiv der deutschen Seewarte* (Hamburg) 36/1, 40 pages, 2 plates.

Schoy 1923 = —, *Die Gnomonik der Araber* (Berlin) [= E. von Bassermann-Jordan, ed., *Die Geschichte der Zeitmessung und der Uhren*, Band I, Lieferung F]; repr. in idem, *Beiträge*, II, pp. 351–447.

Schoy 1924 = —, "Sonnenuhren der spätarabischen Astronomie", *Isis* 6, 332–360; repr. in idem, *Beiträge*, II, pp. 484–512.

Schoy 1927 = —, "ʿAlī ibn ʿĪsā, Das Astrolab und sein Gebrauch", *Isis* 9, 239–54; repr. in idem *Beiträge*, II, pp. 613–628.

Schoy, *Beiträge* = —, *Beiträge zur arabisch-islamischen Mathematik und Astronomie*, ed. F. Sezgin *et al.*, 2 vols. (Frankfurt: Institut für Geschichte der Arabisch-Islamischen Wissenschaften, 1988).

Sédillot, *Traité* = J. J. Sédillot (transl.) *Traité des instruments astronomiques des Arabes*, 2 vols. (Paris, 1834; repr. Frankfurt: Institut für Geschichte der Arabisch-Islamischen Wissenschaften, 1984) [translation of the first half of al-Marrākushī's *Jāmiʿ al-mabādiʾ wa-l-ghāyāt fī ʿilm al-mīqāt*].

Sédillot, *Mémoire* = L. A. Sédillot, *Mémoire sur les instruments astronomiques des Arabes* (Paris, 1844; repr. Frankfurt: Institut für Geschichte der Arabisch-Islamischen Wissenschaften, 1989).

Seeman 1925 = Hugo Seeman (with Th. Mittelberger), "Das kugelförmige Astrolab nach den Mitteilungen von Alfons X. von Kastilien und den vorhandenen arabischen Quellen", in *Abhandlungen zur Geschichte der Naturwissenschaften und der Medizin*, Heft VIII, Erlangen; repr. in Sezgin, *AIOS*.

Sergeyeva & Karpova 1978 = N. D. Sergeyeva and L. M. Karpova, "Al-Farghānī's Proof of the Basic Theorem of Stereographic Projection", Appendix 3 of R. B. Thompson, *Jordanus de Nemore and the Mathematics of Astrolabes:* De Plana Spera (Toronto).

Şeşen 1975-82 = Ramazan Şeşen, *Nawādir al-makhṭūṭāt al-ʿarabīya fī maktabāt Turkiyā*, 3 vols. (Beirut).

Sezgin, *GAS* = Fuat Sezgin, *Geschichte des arabischen Schrifttums*. Band V: *Mathematik bis ca. 430 H* (Leiden: Brill, 1976); Band VI: *Astronomie bis ca. 430 H.* (Leiden: Brill, 1978). Bände X–XI: *Mathematische Geographie und Kartographie im Islam und ihr Fortleben im Abendland. Historische Darstellung* (Frankfurt: Institut für Geschichte der Arabisch-Islamischen Wissenschaften, 2000).

Sezgin, *AIOS* = *Arabische Instrumente in orientalistischen Studien*, ed. F. Sezgin *et al.*, 6 vols. (Frankfurt: Institut für Geschichte der Arabisch-Islamischen Wissenschaften, 1990-91).

Siggel 1942 = Alfred Siggel, "Mitteilungen über das Buch der aufgehenden Sterne des Muḥammad b. Abī 'l-Ḫair al-Ḥasanī", *Quellen und Studien zur Geschichte der Naturwissenschaften und Medizin* 8, 435–437.

Stautz 1994 = Burkhard Stautz, "Die früheste bekannte Formgebung der Astrolabien", in *Ad Radices. Festband zum fünfzigjährigen Bestehen des Instituts für Geschichte der Naturwissenschaften*, ed. A. von Gotstaedter (Stuttgart: Steiner), pp. 315–324.

Stautz 1997 = —, *Untersuchungen von mathematisch-astronomischen Darstellungen auf mittelalterlichen Astrolabien islamischer und europäischer Herkunft* (Bassum: GNT-Verlag).

Steinschneider 1881-87 = Moritz Steinschneider, "Études sur Zarkali, astronome arabe du XIe siècle, et ses ouvrages", *Bullettino di bibliografia e di storia delle scienze matematiche e fisiche* 14 (1881), 171–182; 16 (1883), 493–504; 17 (1884), 765–

794; 18 (1885), 343–360; 20 (1887), 1–36, 575–604.

Stoeffler, *Elucidatio* = Johannes Stoeffler, *Elucidation fabricae ususque astrolabii* (Oppenheim, 1524).

al-Ṣūfī, *Kitābān* = ʿAbd al-Raḥmān al-Ṣūfī, *Two Books on the Use of the Astrolabe*, ed. F. Sezgin (Frankfurt: Institut für Geschichte der Arabisch-Islamischen Wissenschaften, 1986). [Text 1: *Kitāb al-ʿAmal bi-l-asṭurlāb* in 402 chapters, facsimile of MS Istanbul Topkapı Sarayı, Ahmet III 3509. Text 2: *Risāla fī 'l-ʿAmal bi-l-asṭurlāb* in 170 chapters, facsimile of MS Aya Sofia 2642.]

Suter, *MAA* = Suter, *Mathematiker und Astronomen der Araber und ihre Werke* (Leipzig: Teubner, 1900) [also published in *Abhandlungen zur Geschichte der mathematischen Wissenschaften* 10 (1900), 1–285]. "Nachträge und Berichtigungen" in *ibid.* 14 (1902), 157–185. Both reprinted in idem, *Beiträge zur Geschichte der Astronomie im Islam*, ed. F. Sezgin, 2 vols. (Frankfurt: 1986), I, pp. 1–285, and 286–314.

al-Suyūṭī, *Naẓm* = Jalāl al-Dīn ʿAbd al-Raḥmān ibn Abī Bakr al-Suyūṭī [d. 1505], *Naẓm al-ʿiqyān fī aʿyān al-aʿyān*, ed. P. K. Hitti (New York, 1927).

Toomer 1998: see Ptolemy, *Almagest*.

A. Turner 1981 = Anthony John Turner, "William Oughtred, Richard Delamain and the horizontal instrument in seventeenth century England", *Annali dell' Istituto e Museo di Storia della Scienza di Firenze* 6, 99–125, repr. in A. Turner 1993.

A. Turner 1985 = —, *Astrolabes, astrolabe related instruments* (Rockford, IL: Time Museum).

A. Turner 1989 = *Études 1987–1989*, ed. A. J. Turner (Paris: Société Internationale de l'Astrolabe & Institut du Monde Arabe) [Astrolabica, 5].

A. Turner 1993 = —, *Of Time and Measurement* (Aldershot: Ashgate/Variorum).

A. Turner 1994 = —, *Mathematical Instruments in Antiquity and the Middle Ages. An Introduction* (London: Vade-Mecum Press).

A. Turner 2000 = —, "The Anaphoric Clock in the Light of Recent Research", in Folkerts and Lorch 2000, pp. 536–547.

G. Turner 1991 = *Storia delle scienze 1. Gli Strumenti*, ed. Gerald Turner (Milan: Giulo Einaudi).

Ünver 1954 = Süheyl Ünver, "Sur les cadrans solaires horizontaux et verticaux en Turquie", *Archives Internationales d'Histoire des Sciences* 7, 254–66.

Ünver 1969 = —, *İstanbul Rasathanesi* (Ankara: Türk Tarih Kurumu Basımevi).

van Cittert 1954 = P. H. van Cittert, *A Critical Description of the Astrolabes, Noctilabes and Quadrants in the Care of the Utrecht University Museum* (Leiden: Brill).

Varisco 2000 = Daniel Martin Varisco, "Islamic Folk Astronomy", in *Astronomy across Cultures. The History of Non-Western Astronomy*, ed. H. Selin and S. Xiaochun (Dordrecht: Kluwer), pp. 615–650.

Versteegh 1997 = Kees Versteegh, *The Arabic Language* (Edinburgh: Edinburgh University Press).

Viladrich 1982 = Mercè Viladrich, "On the Sources of the Alphonsine Treatise dealing with the Construction of the Plane Astrolabe", *Journal for the History of Arabic Science* 6, 167–71.

Viladrich 1986 = —, *El "Kitāb al-ʿAmal bi-l-asṭurlāb" (Llibre de l'ús de l'astrolabi) d'Ibn al-Samḥ* (Barcelona: Institut d'Estudis Catalans).

Viladrich 1987 = —, "Una nueva evidencia de materiales árabes en la astronomia alfonsi", in *De Astronomia Alphonsi Regis* (Barcelona), pp. 105–116.

Viladrich 2000 = —, "Medieval Islamic Horary Quadrants for Specific Latitudes and their Influence on the European Tradition", *Suhayl* (Barcelona) 1, 273–355.

Wedemeyer 1916 = A. Wedemeyer, "Der Mittagshafir und -halazun von Abul Hassan. Die älteste Meßkarte zur Bestimmung von Sonnenhöhen", *Annalen der Hydrographie und maritimen Meteorologie* 44, 20–29 [reply of C. Schoy and counter-reply of Wedemeyer on pp. 166–168]; repr. in Sezgin *AIOS*.

Wiedemann 1909 = Eilhard Wiedemann, "Zu den Anschauungen der Araber über die Bewegung der Erde", *Mitteilungen zur Geschichte der Medizin und Naturwissenschaften* 8, 1–3; repr. in idem, *Gesammelte Schriften*, I, pp. 287–289.

Wiedemann 1912a = —, "Über die Gestalt, Lage und Bewegung der Erde sowie philosophisch-astronomische Betrachtungen von Quṭb al Dîn al Schîrâzî", *Archiv für die Geschichte der Naturwissenschaften und Technik* 3, 395–422; repr. in idem, *Gesammelte Schriften*, I.

Wiedemann 1912b = —, "Zu den Anschauungen der Araber über die Bewegung der Erde (Nachtrag)", *Mitteilungen zur Geschichte der Medizin und Naturwissenschaften* 11, p. 131; repr. in idem, *Gesammelte Schriften*, II, p. 665.

Wiedemann 1913 = —, "Ein Instrument, daß die Bewegung von Sonne und Mond darstellt, nach al-Bīrūnī", *Der Islam* 4, 5–13; repr. in idem, *Gesammelte Schriften*, II, pp. 718–726.

Wiedemann 1918-19 = —, "Definitionen verschiedener Wissenschaften und über diese verfaßte Werke" (Beiträge zur Geschichte der Naturwissenschaften LVII), *Sitzungsberichte der Physikalischen-Medizinischen Sozietät zu Erlangen* 50-51, 1–32; repr. in idem, *Aufsätze*, II, pp. 431–462.

Wiedemann 1928 = —, "Ibn al-Schâṭir, ein arabischer Astronom aus dem XIV. Jahrhundert", (Beiträge zur Geschichte der Naturwissenschaften LXXIX), *Sitzungsberichte der Physikalischen-Medizinischen Sozietät zu Erlangen* 60, 317–326; repr. in idem, *Aufsätze*, II, pp. 729–738; and in Kennedy & Ghanem 1976.

Wiedemann, *Aufsätze* = —, *Aufsätze zur arabischen Wissenschaftsgeschichte*, 2 vols. (Hildesheim: Olms, 1970).

Wiedemann, *Gesammelte Schriften* = —, *Gesammelte Schriften zur arabisch-islamischen Wissenschaftsgeschichte*, ed. F. Sezgin *et al.*, 3 vols. (Frankfurt: Institut für Geschichte der Arabisch-Islamischen Wissenschaften, 1984-85).

Wiedemann & Frank 1920-21 = E. Wiedemann and J. Frank, "Allgemeine Betrachtungen von al-Bīrūnī in einem Werk über die Astrolabien" (Beiträge zur Geschichte der Naturwissenschaften LXI), *Sitzungsberichte der Physikalischen-Medizinischen Sozietät zu Erlangen* 52-53, pp. 97–121; repr. in Wiedemann, *Aufsätze*, II, pp. 516–540.

Wiedemann & Frank 1921 = —, "Vorrichtungen zur Teilung von Kreisen und Geraden usw. nach al-Bīrūnī", *Zeitschrift für Instrumentenkunde*, 41, 225–236; repr. in Wiedemann, *Gesammelte Schriften*, II, pp. 963–974.

Wiedemann & Hauser 1915 = E. Wiedemann and F. Hauser. "Über die Uhren im Bereich der islamischen Kultur", *Nova Acta. Abhandlungen der Kaiserlich Leopoldinisch-Carolinischen Deutschen Akademie der Naturforscher* (Halle), 100, 1–272; repr. in *idem*, *Gesammelte Schriften*, III, pp. 1211–1482.

Wiedemann & Juynboll 1926 = E. Wiedemann and Th. W. Juynboll, "Avicennas Schrift über ein von ihm ersonnenes Beobachtungsinstrument", *Acta Orientalia* 11/5, 81–167; repr. in Wiedemann, *Gesammelte Schriften*, II, pp. 1117–1203.

Wiedemann & Mittelberger 1926-27 = E. Wiedemann and Th. Mittelberger, "Einleitung von al Zarqâlî zu einer Schrift über die nach ihm benannte Scheibe" (Beiträge zur Geschichte der Naturwissenschaften LXIX), *Sitzungsberichte der Physikalischen-Medizinischen Sozietät zu Erlangen* 58-59 (1926-27), 197–202; repr. in Wiedemann, *Aufsätze*, II, pp. 622–627.

Wiedemann & Suter 1920-21 = E. Wiedemann and H. Suter, "Über al-Bīrūnī und seine Schriften" (Beiträge zur Geschichte der Naturwissenschaften LX), *Sitzungsberichte der Physikalischen-Medizinischen Sozietät zu Erlangen* 52-53, 55–96; repr. in Wiedemann, *Aufsätze*, II, pp. 474–515.

Wiedemann & Würschmidt 1916 = E. Wiedemann and J. Würschmidt, "Über eine arabische kegelförmige Sonnenuhr", *Archiv für die Geschichte der Naturwissenschaften und Technik* 7, 359–376; repr. in Wiedemann, *Gesammelte Schriften*, II, pp. 830–547.

Witkam: see Ibn al-Akfānī.

Woepcke 1858 = Franz Woepcke, "Über ein in der Königlichen Bibliothek zu Berlin befindliches arabisches Astrolabium", *Abhandlungen der Königlichen Akademie der Wissenschaften*, Berlin, offprint of 31 pages; repr. in Sezgin, *AIOS*.

Worell 1944 = W. H. Worrell, "Qusta ibn Luqa on the Use of the Celestial Globe", *Isis* 35, 285–293.

Worell & Rufus 1944 = W. H. Worell and W. C. Rufus, "Māridīnī's introduction to the use of the quadrant", *Scripta Mathematica* 10, 170–180.

Würschmidt 1918 = Joseph Würschmidt, "Ein türkisch-arabisches Quadrant-Astrolab", *Archiv für Geschichte der Naturwissenschaften und der Technik* 8, 167–81; repr. in Sezgin, *AIOS*.

Würschmidt 1919 = —, "Die Bestimmung der krummen Stunden der Deklination und der Gebetszeiten mittels des Astrolabs", *Mitteilungen zur Geschichte der Medizin und Naturwissenschaften* 18, 183–190; repr. in Sezgin, *AIOS*.

Würschmidt 1928 = —, "Die Schriften Gedosis über die Höhenparallelen und über die Sinustafel (Zum Gebrauch des Quadranten im Islam)", *Sitzungsberichte der Physikalischen-Medizinischen Sozietät zu Erlangen* 60, 127–154; repr. in Sezgin, *AIOS*.

Zinner 1956 = Ernst Zinner, *Deutsche und niederländische astronomische Instrumente des 11.–18. Jahrhunderts* (Munich: Beck).

INDEX OF MANUSCRIPTS QUOTED*

* Manuscripts I have consulted for this study are marked with an asterisk.

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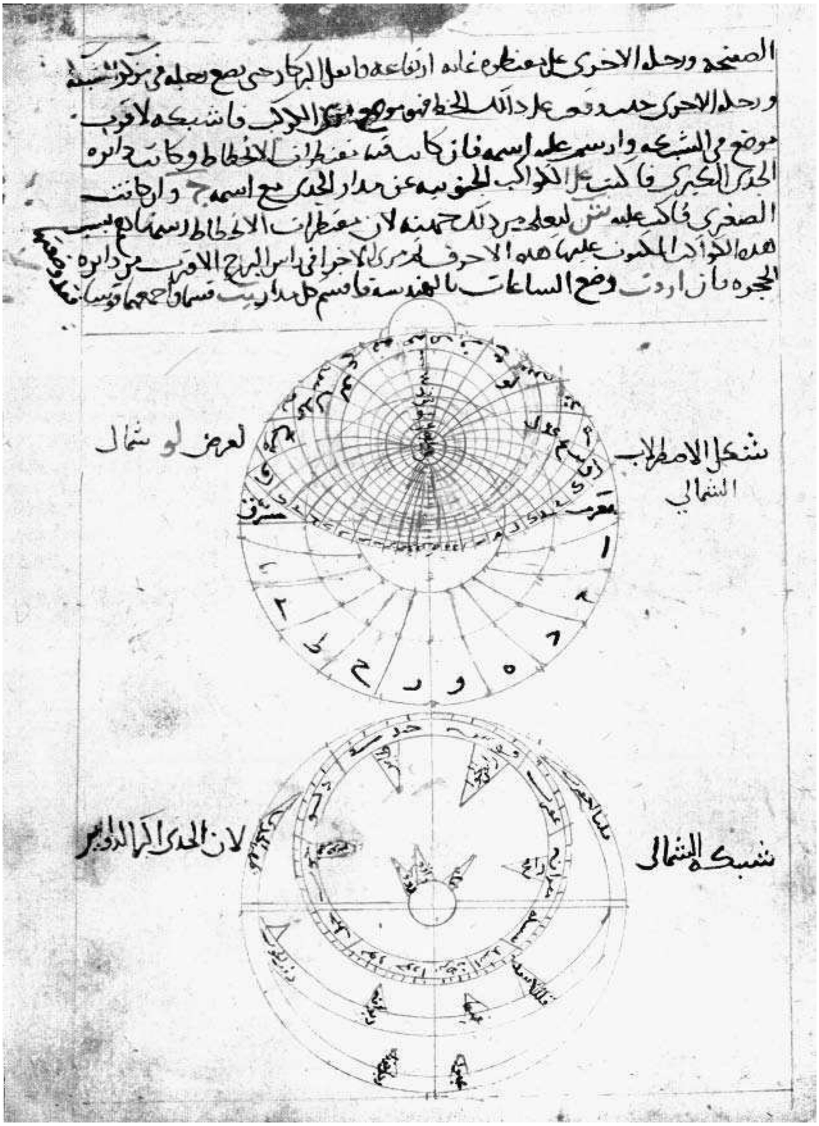

PLATE 1

P:26r – End of Ch. 1, with illustration of the plate and rete of a northern astrolabe for latitude 36° (courtesy of the Institut für Geschichte der Naturwissenschaften, Frankfurt am Main)

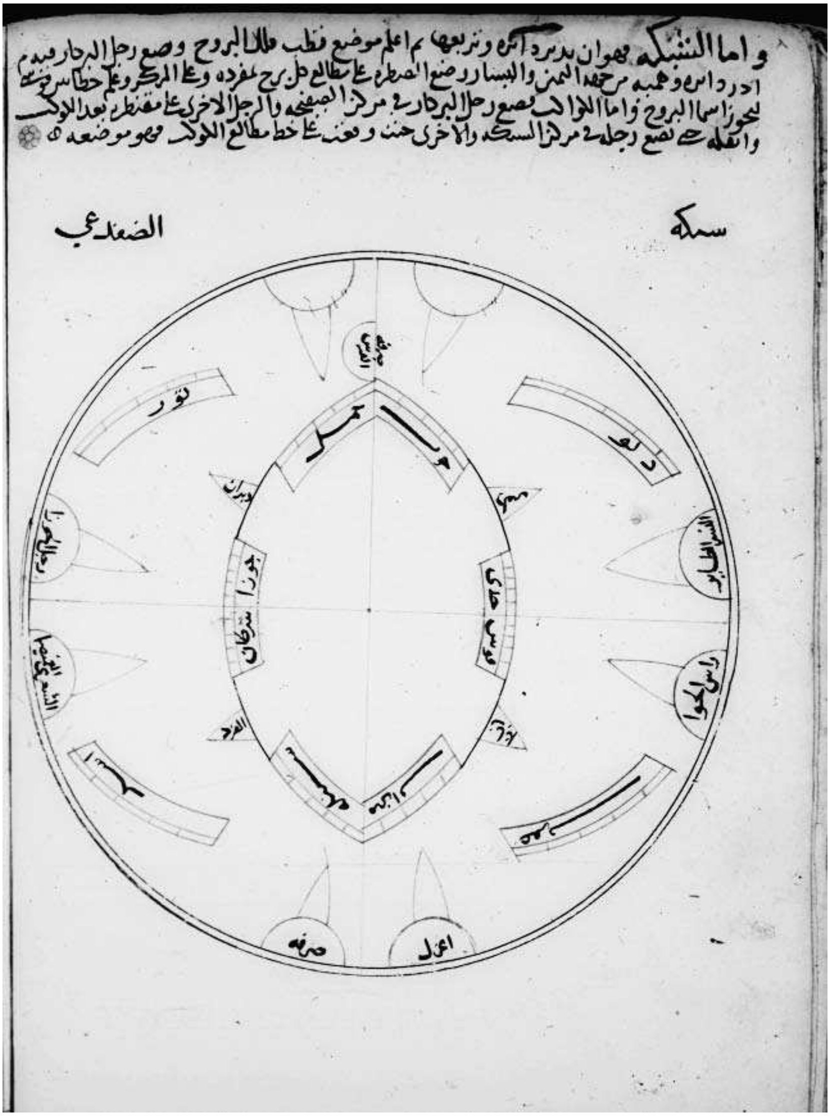

PLATE 2

D:57v – Second half of Ch. 27, with illustration of the rete of the frog astrolabe (courtesy of the Chester Beatty Library, Dublin)

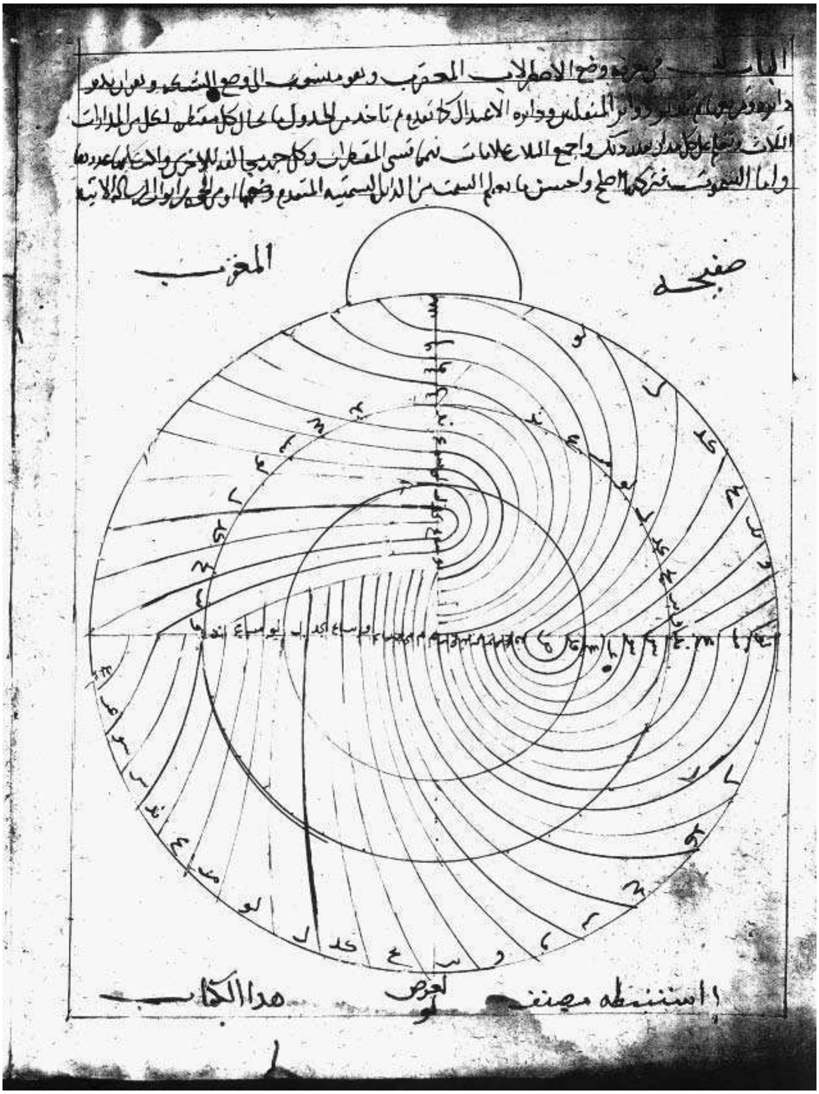

PLATE 3

P:4v – First half of Ch. 34, with illustration of the plate of the scorpion astrolabe for latitude 36° (courtesy of the Institut für Geschichte der Naturwissenschaften, Frankfurt am Main)

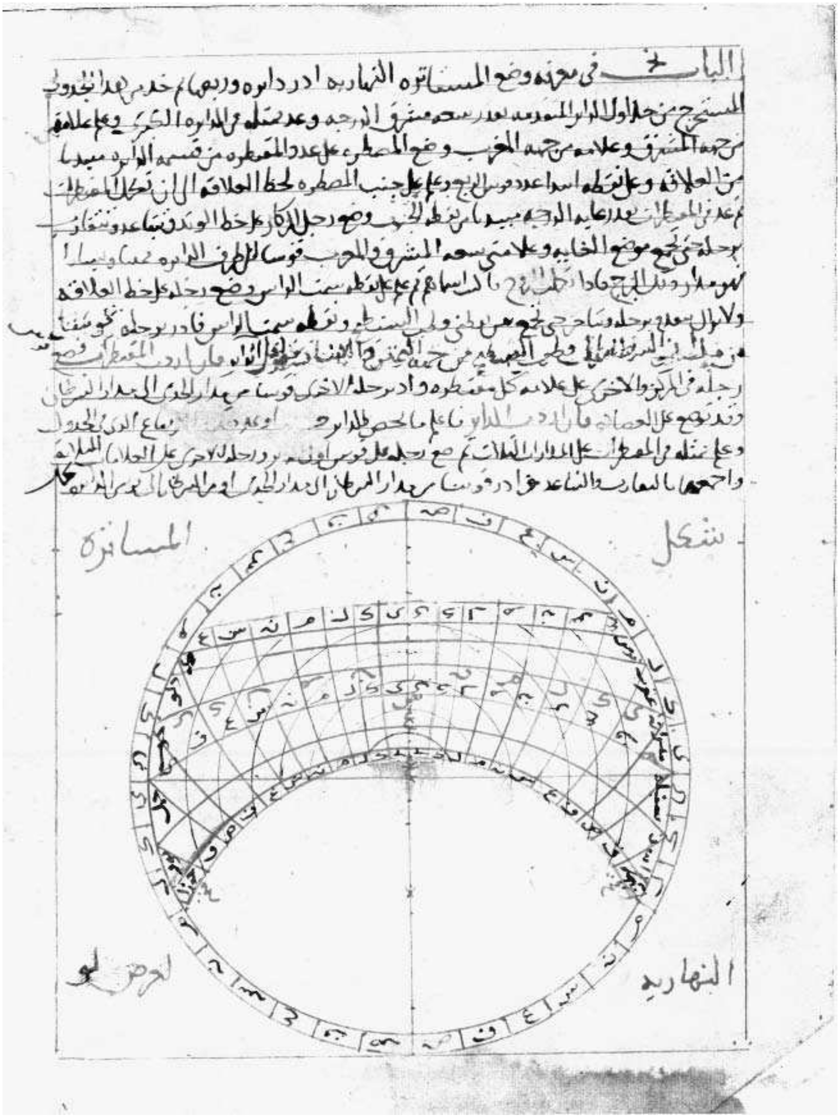

PLATE 4

P:28v – Ch. 53, with illustration of the diurnal *musātira* for latitude 36° (courtesy of the Institut für Geschichte der Naturwissenschaften, Frankfurt am Main)

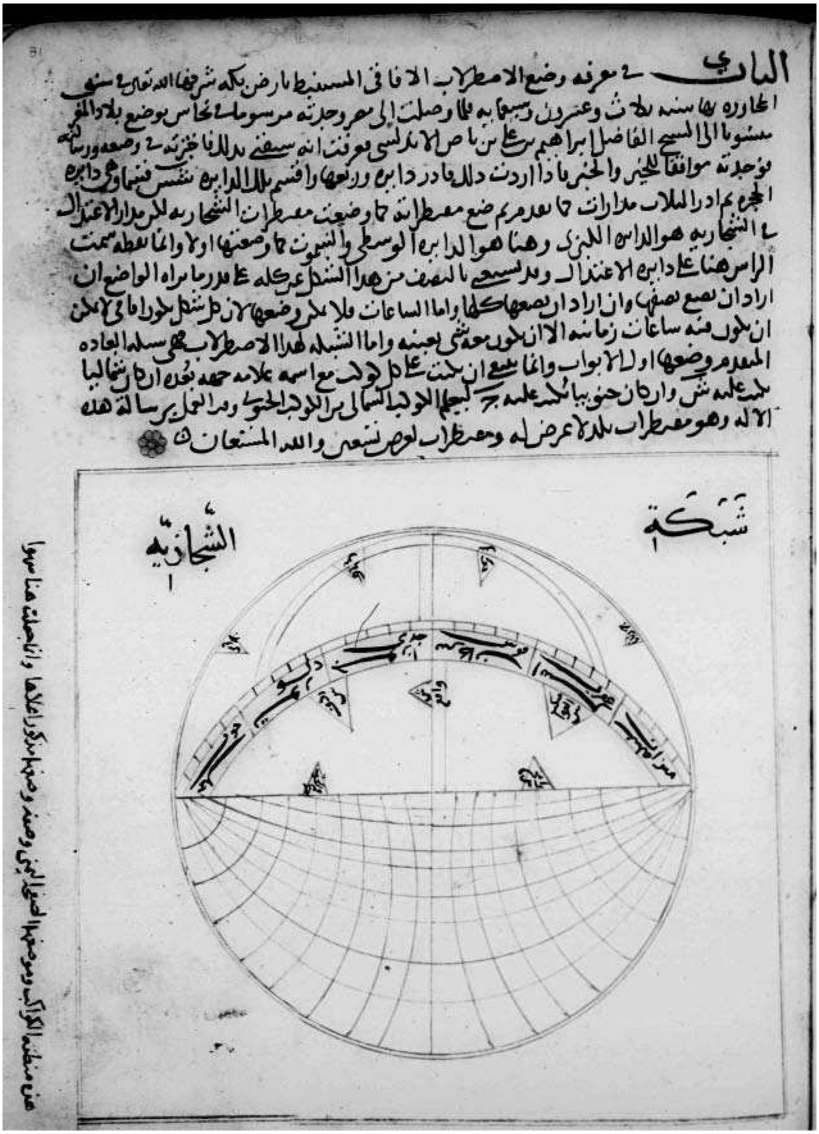

PLATE 5

D:81r – Ch. 10, with illustration of the rete of the universal astrolabe which pertains in fact to the second half of Ch. 9 on f. 80v; the note in the margin warns that their respective illustrations have been inadvertently commuted (courtesy of the Chester Beatty Library, Dublin).

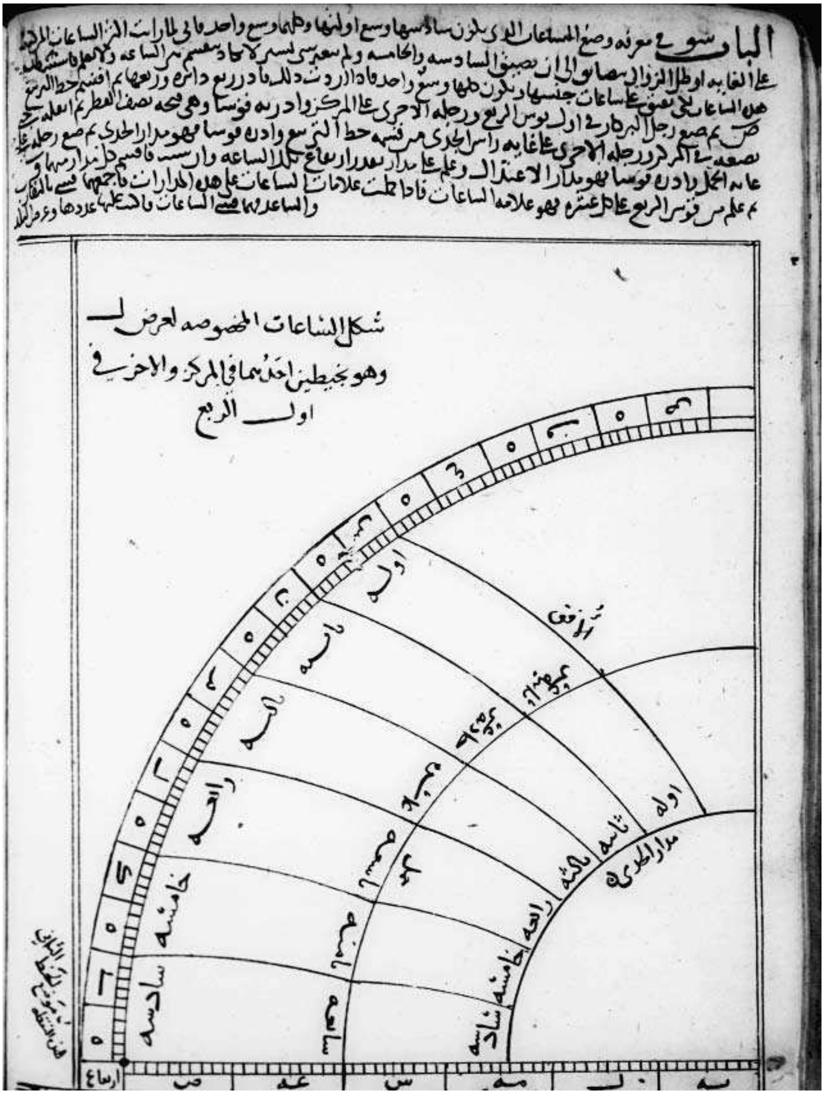

PLATE 6

D88v: – Ch. 66, with illustration of an horary quadrant with almost equidistant hour-lines, for latitude 30° (courtesy of the Chester Beatty Library, Dublin)

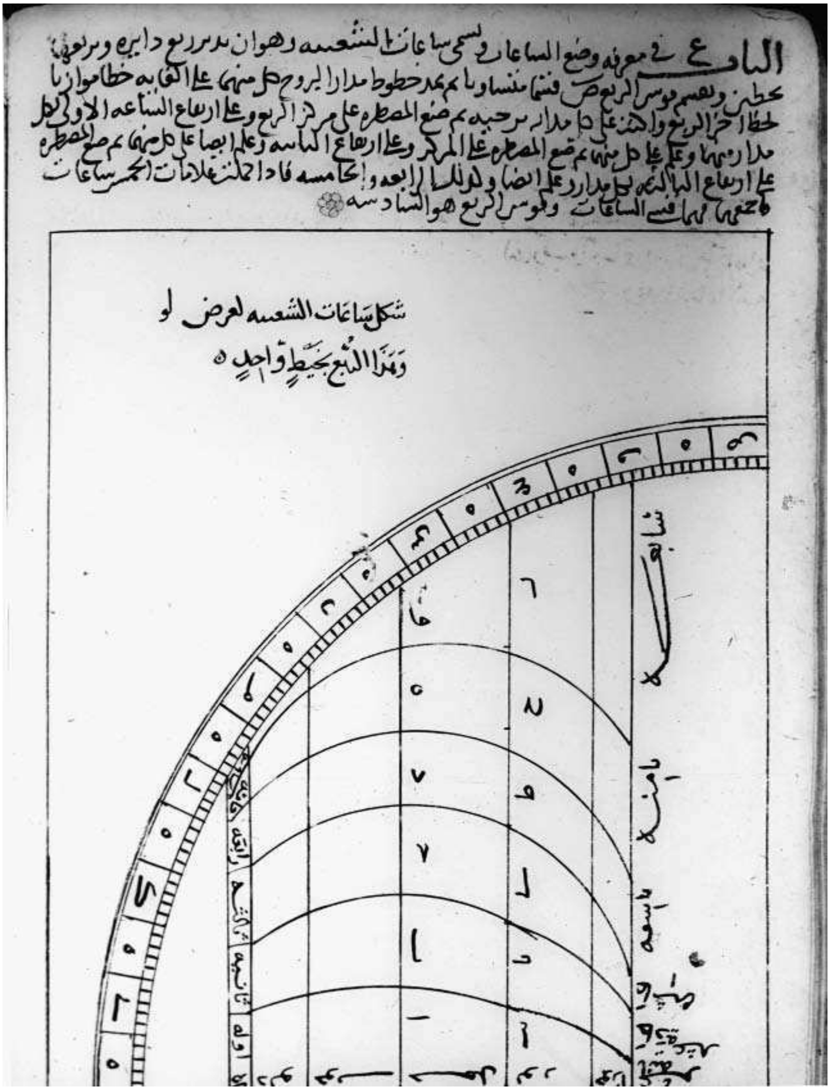

PLATE 7

D:90v – Ch. 70, with illustration of an horary quadrant with vertical straight day-lines, for latitude 36° (courtesy of the Chester Beatty Library, Dublin)

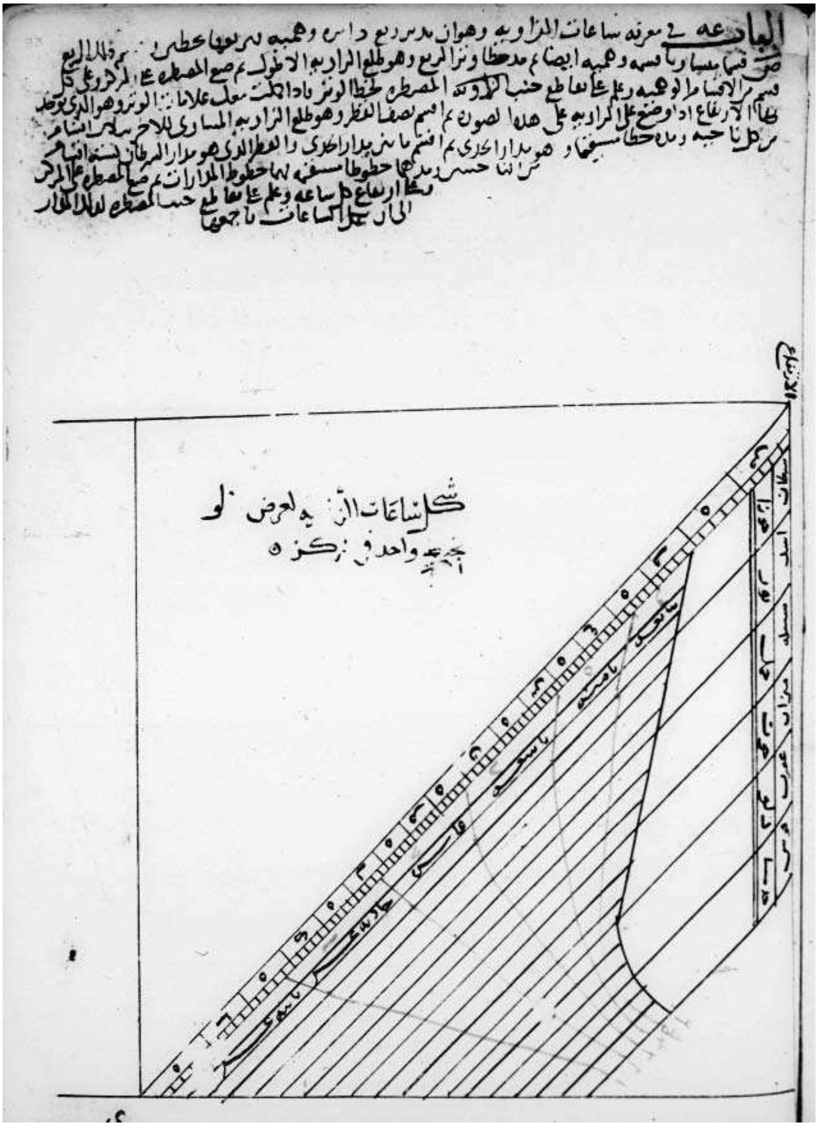

PLATE 8

D:93r – Ch. 75, with illustration of an horary quadrant with diagonal straight day-lines, for latitude 36° (courtesy of the Chester Beatty Library, Dublin)

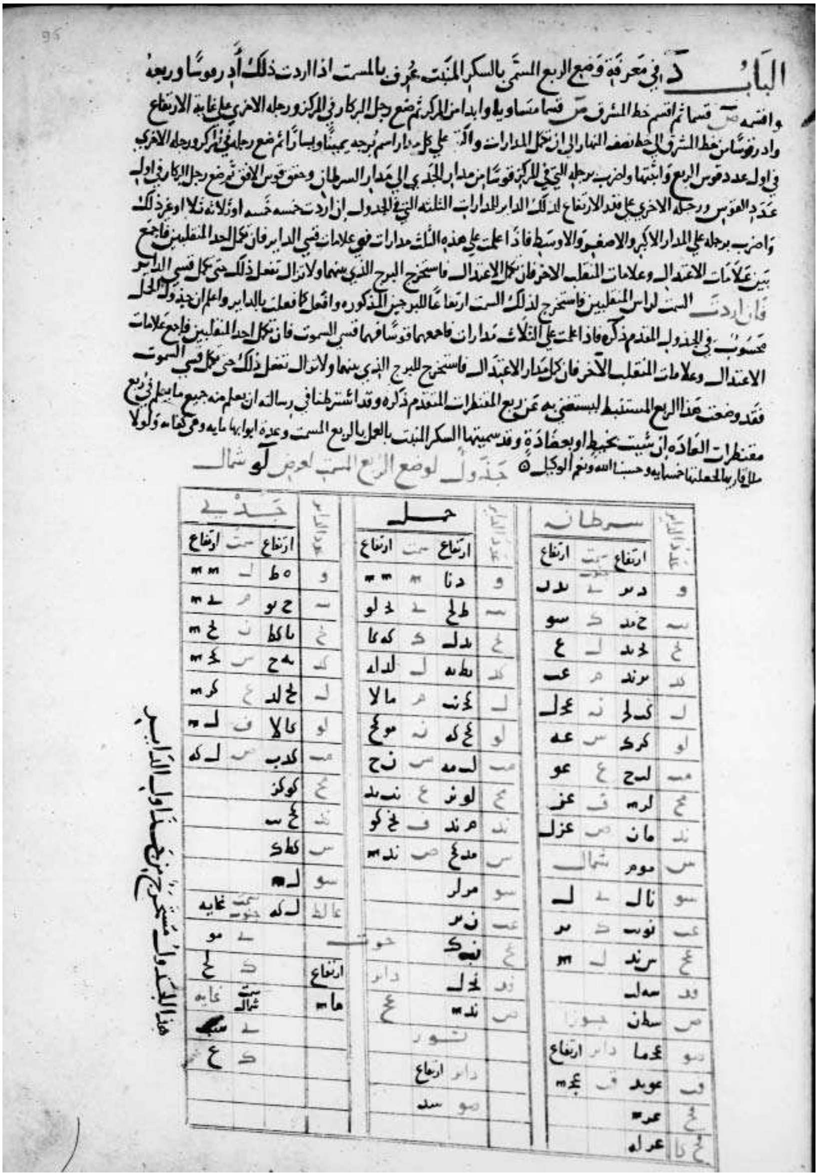

PLATE 9

D:96r – First half of Ch. 4, with a table complied from Najm al-Dīn's huge set of auxiliary tables of the time-arc (*Jadāwil al-Dāʾir*). This page was written by copyist C3 (courtesy of the Chester Beatty Library, Dublin).

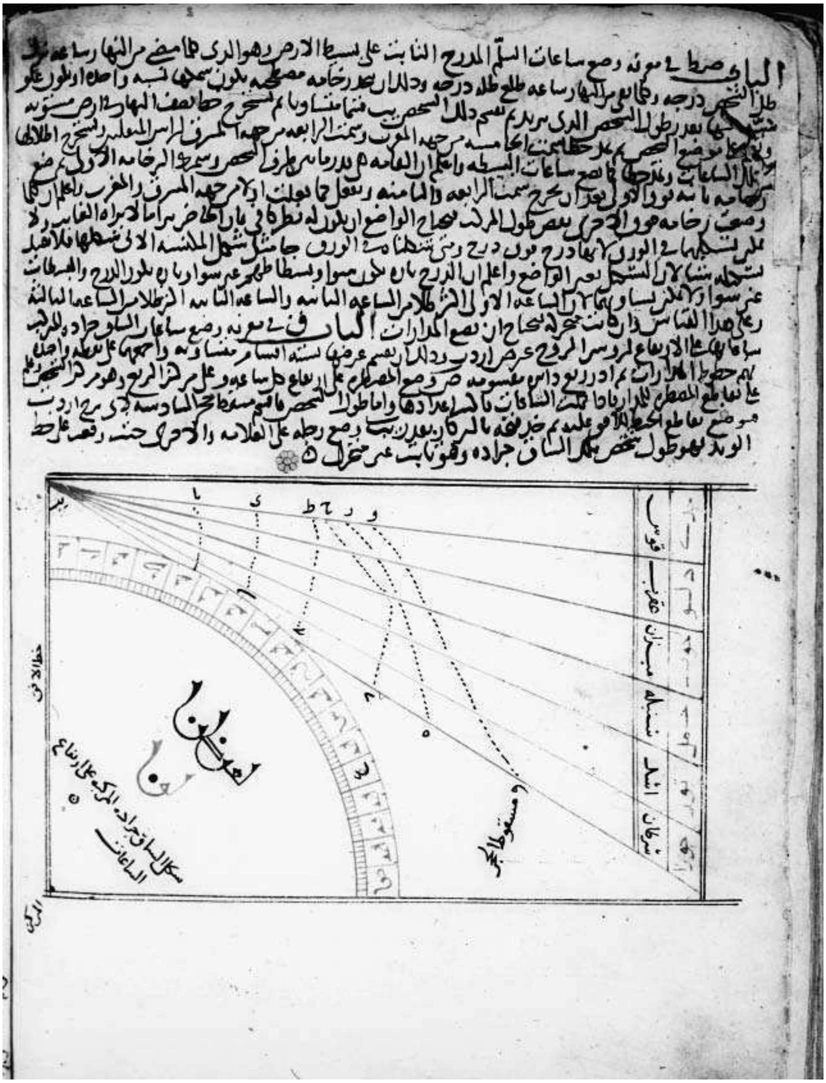

PLATE 10

D:55v – Chs. 99 and 100, the latter with illustration of a gnomonic altitude dial for latitude 36° (courtesy of the Chester Beatty Library, Dublin)

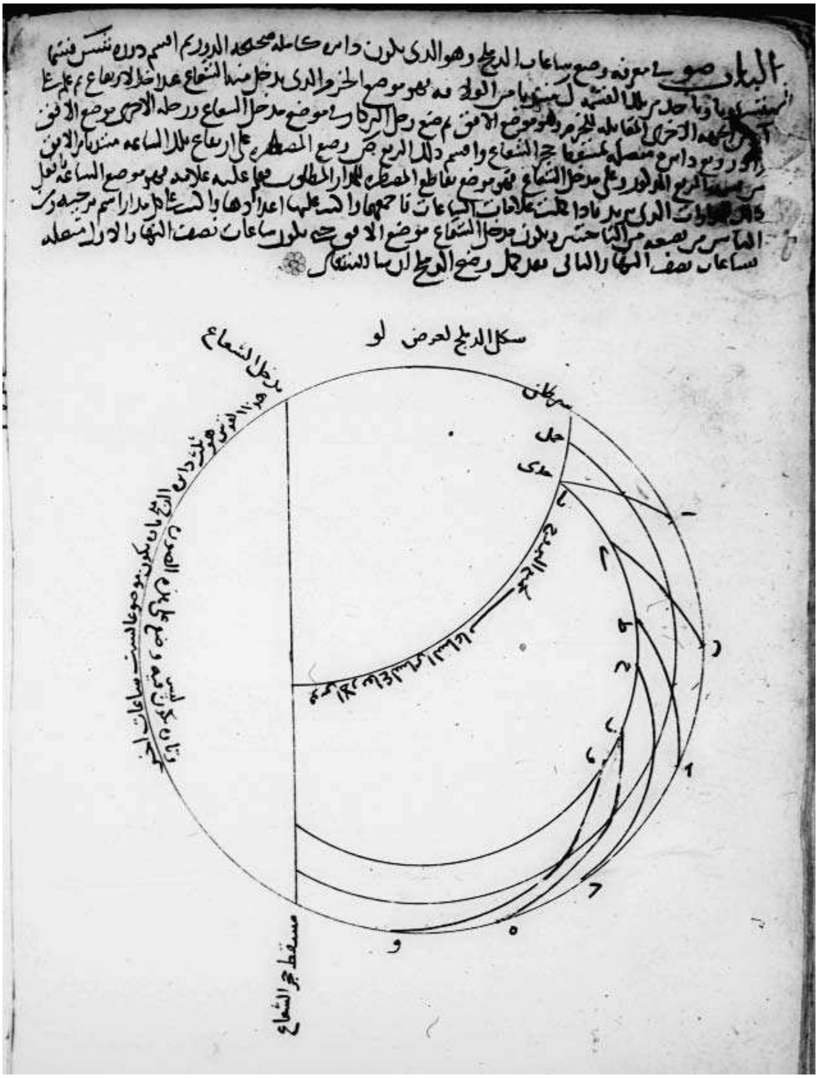

PLATE 11

D:54v – Ch. 96, with illustration of a bracelet dial for latitude 36° (courtesy of the Chester Beatty Library, Dublin)

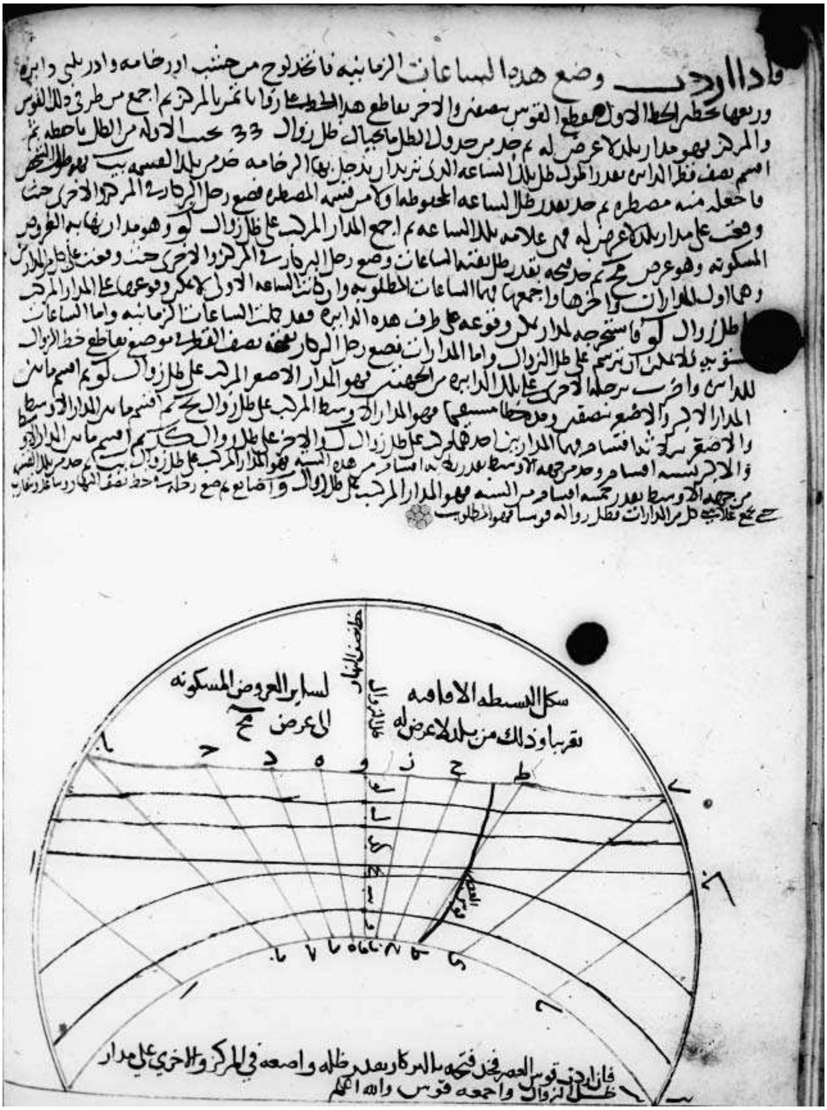

PLATE 12

D:77v – Second half of Ch. 61, with illustration of a universal lunule sundial (courtesy of the Chester Beatty Library, Dublin)

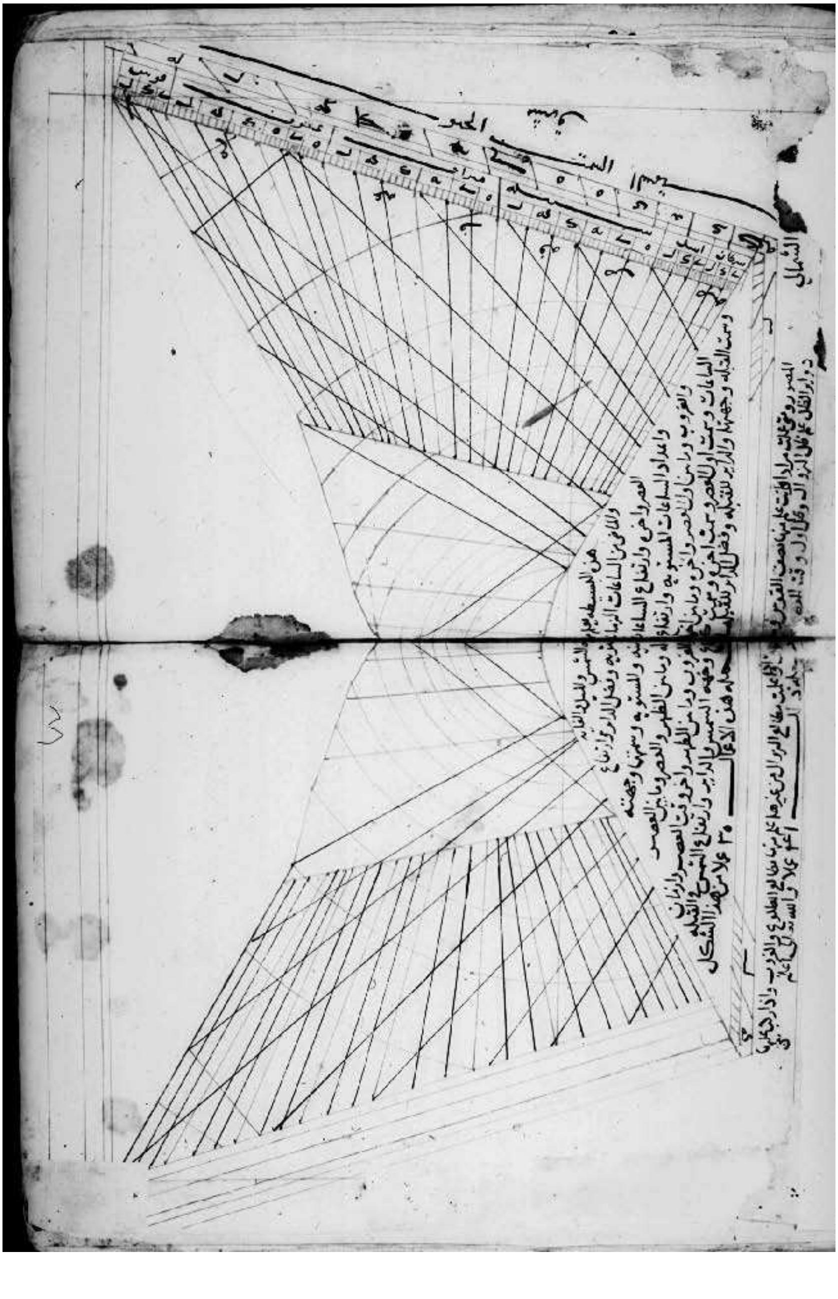

PLATE 13

D:32v-33r – Ch. 103, with illustration of a complex horizontal sundial for latitude 36° (courtesy of the Chester Beatty Library, Dublin)

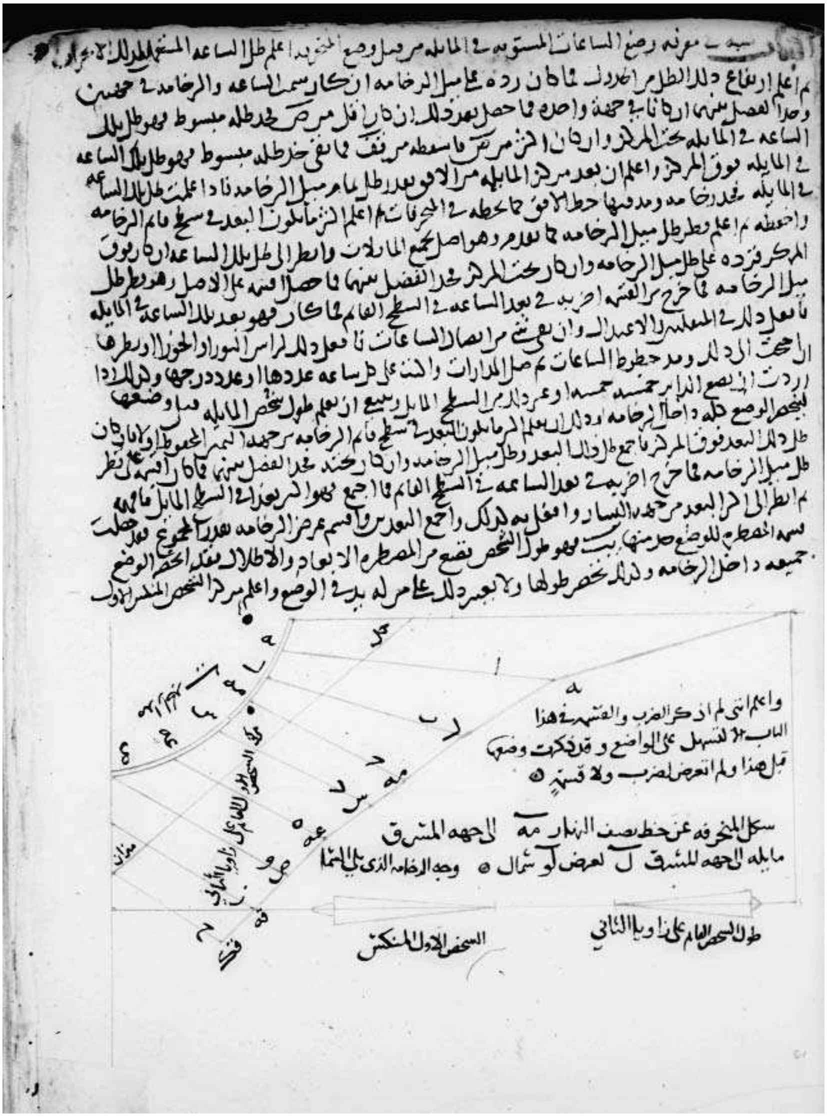

PLATE 14

D:36r – Ch. 115, with illustration of an inclined sundial ($D = -45$, $i = 30$) displaying equal hours before sunset, for latitude 36° (courtesy of the Chester Beatty Library, Dublin)

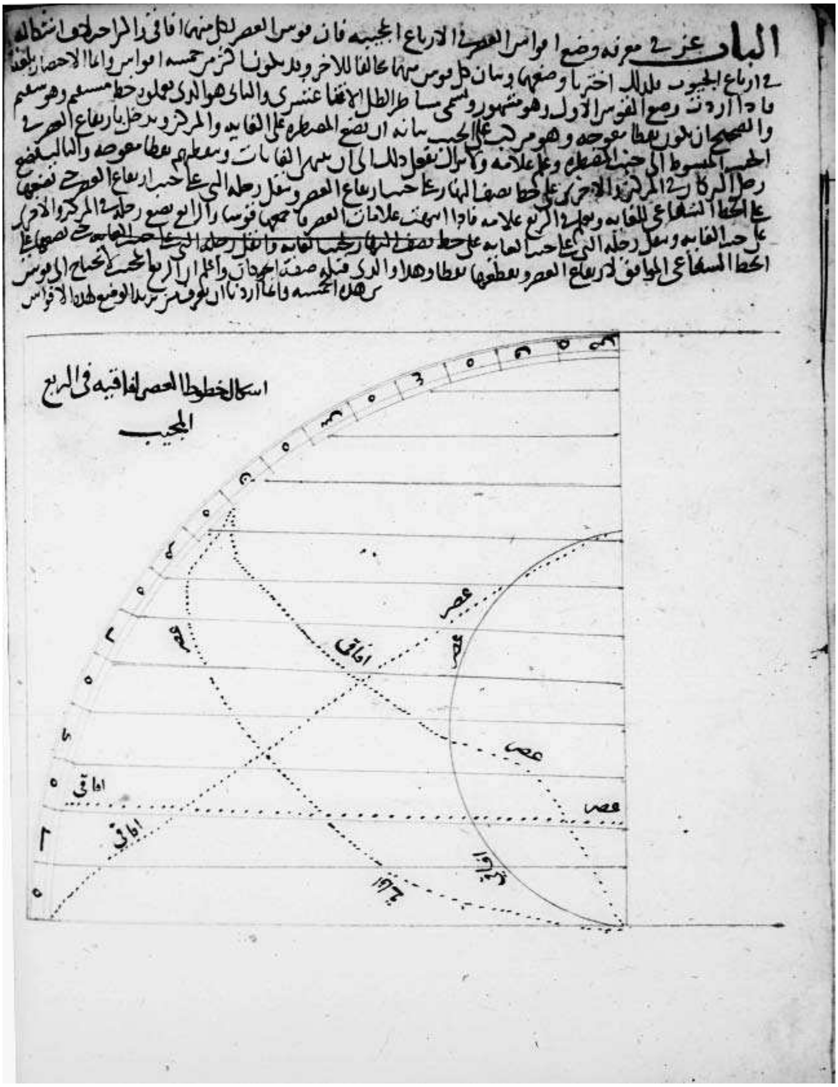

PLATE 15

D:94v – Ch. 77, with illustration of various possibilities of tracing curves for the afternoon prayer (ʿ*aṣr*) on a sine quadrant (courtesy of the Chester Beatty Library, Dublin)

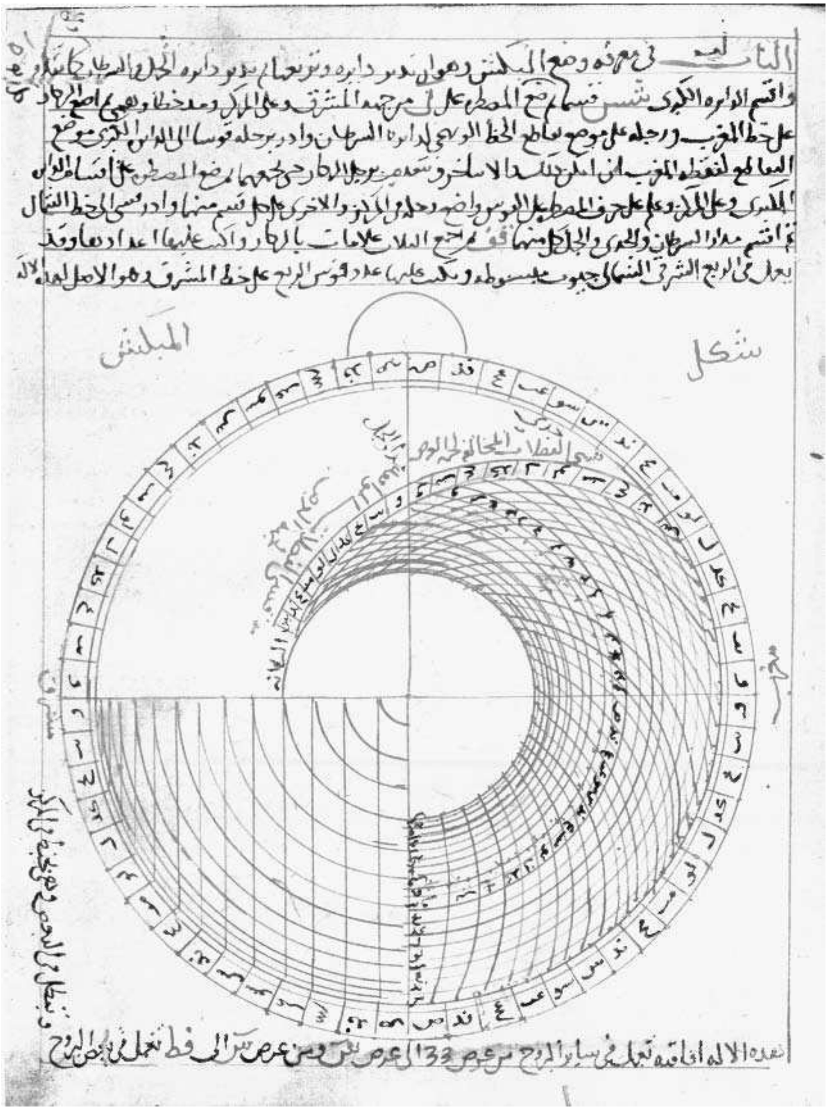

PLATE 16

P:3r – Ch. 32, with illustration of the universal instrument called *al-mubakkash* (courtesy of the Institut für Geschichte der Naturwissenschaften, Frankfurt am Main)

PLATE 17

P:24r – Second half of Ch. 15, with illustration of the rete of a southern *kāmil* astrolabe (courtesy of the Institut für Geschichte der Naturwissenschaften, Frankfurt am Main)

PLATE 18

P:14r – Second half of Ch. 4, with illustration of two versions of the quadrant called *al-sukkar al-munabbat*, which bears markings for the time-arc since rising and for the azimuth, for latitude 36°. Note that this page was drawn upside-down in the manuscript (courtesy of the Institut für Geschichte der Naturwissenschaften, Frankfurt am Main).

دقيقة فأخذنا ظلّه [11] مبسوطًا[9] فوجدناه ذ سجـ [ن] [دقيـ]قة وقسمـ (؟؟) .... [ضعـ]ف ذلك وهو غثكز م دقيقة ثم أخذنا من تلك القسمة يب [12] فهو طول شخص القائمة [على خطّ المشرق] في الوجه الشمالي .... صرت الثالثة (؟) وظلّه لرأس السرطان في تلك المنحرفة ثم أخذنا فتحته بقدر [13] طول الشخص ووضعنا (؟) رجل (؟) ... الأرض (؟) .... لوسط القائمة وأدرنا برجله الأخرى دائرة وهي دائرة الوضع ثم وضعنا [14] المصطرة على مركز هذه الدائرة وعلى كل ساعة من الساعات ألتي يمكن وقوعها في تلك القائمة بيانه متى كان سمت الساعة شمالي فهو [15] [يـ]قع في القائمة على خطّ المشرق في الوجه الشمالي ومتى كان سمت الساعة جنوبي فهو يقع في القائمة على خطّ المشرق في الوجه الجنوبي فاذا علمت ذلك [16] [فمـ]دّ خطّ سمت الساعة على مركز الدائرة ألتي في الأرض وعلى سمته من قسمة الدائرة فموضع تقاطع الخطّ لأصل الحائط أرخى عليه خيط شاقولا (!) وعلّم على [17] تقاطعه لخطّ الأفق فهو موضع بعد تلك الساعة فافهمه ثم اقسم ذلك الخطّ وهو سمت الساعة اثنا عشر قسما وخذ من تلك القسمة بقدر ظلّ الساعة [18] منكوس وضع رجل البركار في موضع بعد الساعة والرجل الاخرى حيث وقعت تحت علامة بعد الساعة على خيط شاقول فهو موضع ظلّ الساعة [19] [و]احفظه لوقت الحاجة لوضع المائلة ثم افعل ذلك للمدارات (!) الذي (!) يمكن وقوعهما في وجه القائمة من جهة الشمال وصل الساعات بين المدارين واكتب [20] في كل مدار منهما اسم برجه واكتب عدد الساعات الواقعة قبل الزوال وبعد الزوال واعلم أنّ طول الشخص هو ما بين (؟؟) مركز الدائرة واصل الحائط أو الرخامة

<شكل> شكل ساعات القائمة على خطّ المشرق والمغرب من الوجه الشمالي لعرض لو

[9] MS مبسوط

وجه الرخامة الذي يلي الأرض — طول الشخص — مدار الجدي، مدار الحمل والميزان، مدار السرطان — خطّ الحادية عشر : يا — خطّ الأفق الغربي وهو خطّ الثانية عشر : يب — نقطة غروب الهمل والميزان، نقطة غروب السرطان

<**ملاحظة**> ولا يمكن أن تقع فيه غير ساعة واحدة في رأس السرطان واحد عشر ساعة تقع في وجهها الذي يلي السماء وهو الشكل الذي قبله وهو إلى السادسة فإنّ الورق لا يمكن أن تسع[7] أظلال الساعات وإنّما يمكن أن تكون في رخامةٍ كبيرةٍ فإنّ ظلّ الحادية عشر كثير وهذا تشكيلهما

NB: Folio **D**:35v is severely damaged. The legible portions are reproduced line by line.

D:35v
[1] **البـــاب** [**قكب في معرفة**] **وضع ال**[**قائم**]**اة** [**بقدر ؟**] **عرض البلد لو**
.... [2] .... من الطلوع إلى الغروب
.... [3] ... بسيط[اة] لعرض
ص لكنّ الأفقين (؟) ... حى الر .... الثلاث (؟) ....
أردت وضعها من قبل أحد .... [4] ... هو ظلّ ... ميل الدرجة .... أوّل
... وقد ... موا على .... أن تأخذ بقدر ظلّ ميل الدرجة [5] من قسمة
طول الشخ[ص] ... رجله ... مركز وتدير قوسا إلى طرفي الافق ص (؟) مد[ا]ر
تلك الدرجة ثم تقسم المدار الأصغر يب [6] والأكبر يب و ...... ساعات و
.... المائلت بمفردها بظلّ الميل خاصّة ولم يذكروا [7] المائلات جميعها
.... و باحد لسائر المائلات[8] وقد تقدّم القول
[8] فيها فاعلم (؟) أولا اخرا (؟؟) .... خطّ .... هو (؟) ص والوج[ه]
الشمالي هو (؟) ...... هو (؟) وجه الرخامة الشمالي إذا كان ميلها جنوب [9]
..... إلى أن تستخرج ..... [سا]عات في الوجه الشمالي لهذا الـ............. لىعدم
لسمت الساعات وأظلالها المنكوسة كما [10] وضعناها في الباب قز (؟) ..... أن
تنظر إلى أقلّ سمت الساعات .... [فوجد]ناه سمت الثالثة وهو ى ند

[7] يسع **MS** [8] اللل لات (!) **MS**

بقي تأخذ ظلّه مبسوطًا[2] فهو ظلّ تلك الساعة في الرخامة المائلة ثم خذ فتحة بالبركار بقدره وتضعه في المركز والرجل الأخرى على خطّ الوتد ومدّه خطًّا وهميًا فهو ظلّ الساعة ثم زد على ظلّ الساعة ظلّ ميل الرخامة فما حصل اقسمه على قطر ظلّ ميل الرخامة فما اجتمع اضر[به في بعد][3] الساعة في قائم سطح الرخامة أعني المنحرفة قبل ميلها فما كان فهو بعد الساعة في المائلة فخذ بقدره فتحة بالبركار وضع رجله في المركز والأخرى حيث وقعت على خطّ المركز الموازي للأفق وأرخى شاقولًا فموضع تقاطع الشاقول لخطّ ظلّ الساعة فهو موضع الساعة فافعل ذلك للمدارات التي يمكن وقوعها في الرخامة وصل بين الساعات دائمًا والمدارات فقد كُمِل الوضع

واعلم أنّ ظلّ الساعات في الوجوه [الأرض]ية[4] دائمًا تحت المركز وفي الوجوه السماوية دائمًا فوق المركز واعلم أنّ أشرف أوضاع الأظلال المائلات وأشرف المائلات الوجه الأرضي وأحسنها المخالف لجهة انحرافه واعلم أنّ البسيطة والمنحرفة وضع المبتدئ والمائلات وضع المتهي فإنّ وضع المائلة أحسن من وضع البسيطة والمنحرفة لأنّ المائلة تعمل من طلوع الشمس إلى غروبها في الوجهين والبسيطة لا يمكن أن تعمل من الطلوع إلى الغروب إلّا إن يكون ...[5] ردادة وكذلك المنحرفة إذا كانت الشمس على تلك الحائط أو الرخامة وظلّ الشخص خارجًا عن وضع الساعات فأحسن المنحرفة أن تعمل من أوّل ما يستنار[6] وجهها إلى حين يظلم فإذا أظلم استنار الوجه الآخر فهذا أحسن وضع المنحرفات ومن أراد أنّه لا يتعرّض للحسّيات فعليه بما ذكرناه أوّلًا والمركز فوق الأفق من الوجه الأرضي دائمًا بقدر ظلّ تمام ميل الرخامة وتنقّط بالأحمر مركز الشخص

<شكل> شكل المنحرفة عن خطّ نصف النهار مه إلى جهة المشرق مائلة إلى جهة المغرب س لعرض لو شمال

---

[2] مبسوط **MS** [3] Hole **MS** [4] Hole **MS** [5] Blank space **MS** [6] يستنر **MS**

ظلّ تلك الساعة تحت المركز وإن اجتمع أكثر من ص فاسقطه من قف وما بقي خذ ظلّه فهو ظلّ تلك الساعة فوق المركز هذا إن كان سمت الساعة ووجه المنحرفة في جهة واحدة وإن كانا في جهتين فانقص ارتفاع الظلّ المستعمل من ميل الرخامة فما بقي خذ ظلّه مبسوطًا فهو ظلّ تلك الساعة تحت المركز فمدّه خطًّا وهميًا موازيًا للأفق ثم انظر إن كان الظلّ فوق المركز فزده على ظلّ ميل الرخامة وإن كان تحت المركز فخذ الفضل بينهما اقسمه على قطر ظلّ <ميل> المائلة واضرب ما حصل في بعد الساعة لتلك المنحرفة فما اجتمع فهو البعد في المائلة وأمّا السموت فقد تقدّم الوضع وإنّما أردنا أن نزيده

بيان : واعلم أنّ عرض الرخامة هو من المركز القائم على الزاوية إلى أصل الرخامة واعلم أن بعد المركز من الأفق بقدر ظلّ تمام ميل الرخامة أبدًا والمركز تحت الأفق في الوجه الشمالي دائمًا

<**شكل**> شكل المنحرفة عن خطّ نصف النهار مه إلى جهة المشرق مائلة إلى جهة المغرب س لعرض لو شمال

وجه الرخامة الذي يلي السماء — مركز — طول الشخص — بعد المركز من الأفق ك مز — سمت شمال \ جنوب — مدار السرطان، حمل \ ميزان، مدار الجدي — أولة (!)، ثانية، ... ، سادسة \ خطّ الزوال

<**ملاحظة**> الساعات الزمانية هي[10] الخطوط السود (!) — السموت هي[11] الخطوط الحمر (!) — يعلم منها الساعات الزمانية وسمتها وجهته وسعة المشرق لعرض لو شمال

البـــاب قكا في معرفة وضع المائلات الموضوعة في الجهة المخالفة لجهة انحرافها وذلك في الوجه الذي يلي الأرض D:35r

وهو أن تعلم بعد الساعة وظلّ المستعمل في تلك المنحرفة في الرخامت التي[1] تريد وضعها ثم تعلم ارتفاع الظلّ المستعمل وتسقط منه ميل الرخامة فما

[10] MS هم [11] MS هم [1] MS الذي

ثم استخرج البعد لذلك الظلّ **بيانه** أن تعلم السمت لعدد تلك المقنطرة لتلك الدرجة ثم تعلم البعد لذلك السمت في سطح قائم الرخامة وتحفظه ثم تجمع ظلّ تلك المقنطرة لتلك المائلة مع ظلّ ميل الرخامة فما اجتمع اقسمه على قطر ظلّ ميل الرخامة فما حصل اضربه في البعد المحفوظ فما كان فهو بعد تلك المقنطرة فخذ بقدره من طول شخص المائلة وضع رجله في المركز والأخرى على خطّ المركز الموازي للأفق فعلّم علامة وأرخى من تلك العلامة شاقولًا على ظلّ المقنطرة الذي عرفته فموضع تقاطع الشاقول لخطّ ظلّ المقنطرة فهو موضع المقنطرة فافعل ذلك لسائر خطوط السموت والمقنطرات فإن شئت أن تخطّها[6] خطوطًا أو نقطًا فهي[7] المقنطرات فاكتب عليها أعدادها بين المقنطرات وخطوط السموت فقد كُمِلت فأفهم تصب

<**شكل**> شكل المنحرفة عن خطّ نصف النهار يَ إلى جهة المغرب لعرض لوَ شمال والعمل في الوجه الأرضي مائلة يَ إلى جهة المشرق

طول الشخص — سمت شمال \ جنوب — <قسي المقنطرات> — مدار السرطان، <مدار الحمل>، مدار الجدي — أولة (!)، ثانية، ... ، رابعة

<**ملاحظة**> تُعلم منها الساعات وارتفاعها وسمتها وجهته وسعة المشرق وارتفاع لا سمت له

البـــاب قكَ في معرفة وضع المائلات التي ميلها[8] إلى غير جهة انحرافها في الوجه الذي يلي السماء **D**:34v

وهو أعرف المائلات وأعجبها فإنّي لم أرى أحدًا ذكر طريقتها ولا رأيت شكلها ومعرفة وضعها من غير حساب أن تنظر إلى الجدول المتقدّم ذكره وتضعها منه كما وضعت غيرها من غير حساب ولا انحراف وإن أردت أن تضعها من جهة الحساب فتعلم انحراف تلك المائلة ثم تعلم أبعاد الساعات وأظلالها[9] لتلك الانحراف وزده على ميل الرخامة فإن اجتمع أقلّ من صَ فخذ ظلّه مبسوطًا فهو

[6] **MS** تخطهم [7] **MS** فهم [8] **MS** مىها [9] **MS** وأظلالهم

وجه الرخامة الجنوبي — طول الشخص — خطوط السمت: جنوب \ شمال — السمت الجنوبي \ السمت الشمالي — قسي المقنطرات — مدار الجدي، ⟨مدار الحمل⟩، مدار السرطان

⟨**ملاحظة**⟩ اعلم أنّ خطوط السمت بالأحمر وقسي المقنطرات بالأسود وجهة السمت مكتوبة

⟨البابان ١١٧ و ١١٨ ناقصان⟩

الباب قيط في معرفة وضع الساعات الزمانية والمقنطرات والسموت في المائلات في وجه الرخامة الذي يلي الأرض D:34r

أمّا الساعات فقد تقدّم معرفة وضعها وأمّا السموت فتعلّم بعدها[4] في السطح القائم للرخامة وتحفظه ثم تجمع ظلّ ميل الرخامة وظلّ تمام ميلها فما اجتمع اقسمه على قطر ظلّ ميل الرخامة فما خرج من القسمة خذ بمثله من قسمة شخص المائلة وضع رجل البركار في موضع تقاطع خطّ الأفق لخطّ الوتد والأخرى حيث وقعت على خطّ الأفق فعلّم علامة واحفظها ثم اقسم عرض الرخامة س وخذ من تلك القسمة بقدر جيب ميل الرخامة بفتحة بالبركار واقسم تلك الفتحة يب وخذ منها بقدر بعد ذلك السمت في المنحرفة وضعه في موضع تقاطع الوتد لأصل المائلة فعلّم علامة في أصل الرخامة ومدّه خطًّا إلى العلامة المحفوظة فهو خطّ السمت المطلوب فافعل ذلك إلى السمت الذي يمكن وقوعه في المائلة واكتب عليه عدده وجهته

وأمّا المقنطرات فخذ الظلّ المستعمل في سطح قائم الرخامة بعدد تلك المقنطرة واعلم الارتفاع لذلك الظلّ فما كان اسقط منه ميل الرخامة فما بقي خذ ظلّه مبسوطًا[5] فهو ظلّ تلك المقنطرة في تلك المائلة فخذ بقدره من طول الشخص للمائلة وضع رجل البركار في مركزه والرجل الأخرى حيث وقعت تحت المركز أعني على خطّ الوتد فمدّه خطًّا موازيًا للأفق

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[4] بعدهم MS [5] مبسوط MS

على الواضع وقد ذكرتُ وضعها قبل هذا ولم أتعرّض لضرب ولا قسمة

<شكل> شكل المنحرفة عن خطّ نصف النهار إلى جهة المشرق مه مائلة إلى جهة المشرق ل لعرض لو شمال

وجه الرخامة الذي يلي السماء — مركز الشخص المنكّس الأوّل — مركز الشخص الأوّل (!!) القائم على زوايا (!) الثاني — <طول> الشخص الأوّل المنكّس — طول الشخص القائم على زوايا (!) الثاني — مدار الجدي، حمل \ ميزان، <مدار السرطان>

D:36v

البـــاب قيو في معرفة وضع منحرفة يُعلم منها الارتفاع والسمت في أيّ وقت شئت ولم تتعرّض (؟)[1] [لانحرافها ولا] لطول الشخص ولا لمركزه

وذلك أن تدير دائرة في أرض مستوية وتخرج الجهات ومدّ خطوط السموت كما تقدّم عشرة عشرة أو خمسة خمسة أو غير ذلك وعلّم على مواضع السمت في أصل الرخامة أو الحائط وأرخى على تلك العلامة شاقولًا فهو خطّ السمت واكتب عليه عدده وجهته ثم اقسم من علامة السمت إلى مركز الدائرة على خطّ السمت الذي في الأرض يب قسمًا وخذ من[2] تلك القسمة بقدر ظلّ منكوس عدد المقنطرة الذي تريد إن شئت عشرة عشرة أو خمسة خمسة أو ستّة ستّة أو غير ذلك وضع رجل البركار في موضع تقاطع خطّ السمت للأفق وعلّم برجله الأخرى علامة على خطّ السمت الذي في سطح قائم الرخامة فافعل ذلك لجميع السموت ثم اجمع علامات المقنطرات وإن أردت أن ترسم المدارات فينبغي[3] أن يحصر الظلّ ومن أراد أنّه لا يحصره ولا يرسم المدارات وتكمل خطوط السموت إلى أصل الرخامة والمقنطرات إلى طرفي الرخامة يمينًا ويسارًا

<شكل> شكل المنحرفة عن خطّ نصف النهار مه إلى جهة المشرق يعلم منها الارتفاع والسمت وجهته لعرض لو شمال وسعة المشرق وارتفاع لا عرض له والغاية والميل وجهته

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[1] تتعرّض (؟)] **MS** تعرض في [2] **MS** وخذ ومن [3] **MS** لتسغي

من ص فاسقطه من قف فما بقي خذ ظلّه مبسوطًا فهو ظلّ تلك الساعة في المائلة فوق المركز

واعلم أنّ بعد مركز المائلة من الأفق بقدر ظلّ تمام ميل الرخامة فإذا علّمت ظلّ تلك الساعة في المائلة فخذ رخامة ومدّ فيها خطّ الأفق كما تخطّه في المنحرفات ثم اعلم أكثر ما يكون البعد في سطح قائم الرخامة واحفظه ثم اعلم قطر ظلّ ميل الرخامة كما تقدّم وهو أصل لجميع المائلات وانظر إلى ظلّ تلك الساعة إن كان فوق المركز فزده على ظلّ ميل الرخامة وإن كان تحت المركز فخذ الفضل بينهما فما حصل اقسمه على الأصل وهو قطر ظلّ ميل الرخامة فما خرج من القسمة اضربه في بعد الساعة في السطح القائم فما كان فهو بعد تلك الساعة في المائلة فافعل ذلك في المنقلبين والاعتدال وإن بقي شيء من اتّصال الساعات فافعل ذلك لرأس الثور والجوزاء أو نظرها إن احتجتَ إلى ذلك ومدّ خطوط الساعات ثم صل المدارات واكتب على كلّ ساعة عددها أو عدد درجها وكذلك إذا أردت أن تضع الدائر خمسة خمسة أو غير ذلك من السطح المائل

وينبغي أن يُعلم طول شخص المائلة قبل وضعها ليحصر الوضع كلّه داخل الرخامة وذلك[11] أن تعلم أكثر ما يكون البعد في سطح قائم الرخامة من جهة اليمين المحفوظة أوّلًا فإن كان ظلّ ذلك البعد فوق المركز فاجمع ظلّ ذلك البعد وظلّ ميل الرخامة وإن كان تحته فخذ الفضل بينهما فما كان اقسمه على قطر ظلّ ميل الرخامة فما خرج اضربه في بعد الساعة في السطح القائم فما اجتمع فهو أكثر بعدًا في السطح المائل فافهمه ثم انظر إلى أكثر البعد من جهة اليسار وافعل به كذلك واجمع البعدين واقسم عرض الرخامة بقدر المجموع فقد حصلت قسمة المصطرة للوضع خذ منها يب فهو طول الشخص فضع من المصطرة الأبعاد والأظلال فقد انحصر الوضع جميعه داخل الرخامة وكذلك يحصر طولها ولا يعسر ذلك على من له يد في الوضع واعلم

<**ملاحظة**> واعلم أنّني لم أذكر الضرب والقسمة في هذا الباب إلّا لتسهل

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[11] اوذلك **MS**

تقاطع المصطرة لأصل المنحرفة واحفظها [... فأرخى شا]قولًا على تلك العلامة وعلّم على موضع <تقاطع> الخيط للأفق فهو موضع بعد الساعة فافهمه ثم اعلم ظلّ منكوس تلك الساعة وضع [رجل البركار] في مركز الدائرة والرجل الأخرى على العلامة المحفوظة واقسم تلك الفتحة يب قسمًا وخذ من تلك القسمة بقدر ظلّ الساعة <منكوس بالبركار وضع رجله على موضع تقاطع الشاقول للأفق> و <الرجل> الأخرى حيث وقعت على خيط الشاقول فهو موضع تلك الساعة فافعل ذلك للمنقلبين واجمع الساعات وكلّ المدارات وأمّا مدار الاعتدال فعلّم على تقاطع خطّ المشرق لأصل المنحرفة وأرخى عليه شاقولًا فموضع تقاطع الشاقول لخطّ الأفق فهو أفق الحمل ثم اقسم خطّ الزوال الذي في الأرض يب وخذ بقدر ظلّ السادسة منكوس بالبركار وضع رجله موضع تقاطع خطّ الزوال للأفق والرجل الأخرى حيث وقعت على خطّ الزوال فهو موضع سادسة الحمل <وصله> إلى أفقه وكذلك إن أردت وضع الدائر خمسة خمسة أو عشرة عشرة أو ثلاثة ثلاثة أو غير ذلك

<شكل> شكل المنحرفة عن خطّ نصف النهار مه إلى [جهة ال]مشرق لعرض لو شمال ساعاتها مستوية وهو الدائر خمسة عشر خمسة عشر

وهذا الوجه الجنوبي — خطّ الأفق — خطّ الزوال — المركز — طول الشخص — مدار الجدي، ميزان، مدار السرطان — عصر

البـــاب قيه في معرفة وضع الساعات المستوية في المائلة من قبل وضع المنحرفة D:36r

اعلم ظلّ الساعة المستعمل لذلك الانحراف ثم اعلم ارتفاع ذلك الظلّ من الجدول فما كان زده على ميل الرخامة إن كان سمت الساعة والرخامة في جهتين وخذ الفضل بينهما إن كانا في جهة واحدة فما حصل بعد ذلك إن كان أقلّ من ص فخذ ظلّه مبسوطًا[10] فهو ظلّ تلك الساعة في المائلة تحت المركز وإن كان أكثر

[10] MS مبسوط

الوجه الأرضي وإن انحططت[6] الشمس قليلًا استنار الوجه الأرضي وأظلم الوجه السمائي واللّه أعلم

<شكل> شكل المنحرفة عن خطّ نصف النهار نَ مائلة إلى جهة المشرق يَ

وجه الرخامة الذي يلي الأرض وهي تعمل من أوّل النهار إلى آخر لثالثة وتظلم

D:32v–33r **<البــــاب قيجَ في معرفة البسيطة التي تعلم منها ٤١ عملا>**[7]

هذه البسيطة تعلم منها درجة الشمس والميل والغاية والماضي من الساعات الزمانية والمستوية وفضل الدائر وارتفاع العصر وآخره وارتفاع الساعات الزمانية والمستوية وسمتها وجهته وأعداد الساعات المستوية وارتفاع لا سمت له وما بين الظهر والعصر وما بين العصر والغروب وما بين أوّل العصر وآخره وما بين آخر العصر والغروب وما بين الظهر وآخر وقت العصر وأزمان الساعات وسمت أوّل العصر وسمت آخره وسمت كلّ ارتفاع وجهة الشمس والدائر وارتفاع الشمس في القبلة وسمت القبلة وجهتها والدائر للقبلة وفضل الدائر للقبلة فجملة هذه الأعمال ٣٠ عملًا من هذا الشكل المصوّر ومتى عملت مُزادًا[8] كانت علم منها نصف القوس وسعة المشرق وإذا علّمت مطالع الزوال من غيرها علم منها مطالع الطلوع والغروب وإذا رُكِب عليها دوائر الظلّ علم ظلّ الزوال وظلّ أوّل وقت العصر وآخره فجملة ذلك ٤١ عملًا واللّه تعالى أعلم

<شكل>

D:33v [**البــــاب قيدَ في معرفة وضع الساعات المستوية في المنحرفات** ....]

[...... وهو أن تدير دائرة][9] في أرض مستوية وإخراج الجهات ومدّ خطّ نصف النهار وخطّ المشرق والمغرب ثم اعلم سمت تلك الساعة [من جدول] البسيطة المتقدّم وضع المصطرة على السمت وعلى المركز وعلّم علامة على موضع

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[6] انحمطت MS [7] There is no chapter heading accompanying the text on **D**:32v–33r, but since it occurs between Chapters 112 and 114 without possible interruption, it is natural to consider it as Chapter 113. [8] مزاد **MS** [9] The beginning of the first lines is illegible in the **MS**

فأرخى عليه شاقولًا فهو وتد الأرض وخذ فتحة البركار بقدر ظلّ تمام ميل الرخامة وضع رجله في المركز المذكور واضرب برجله الأخرى على خطّ الوتد فهو [موا]ضع الأفق لتلك المائلة فمدّ خطًّا بغير نهاية

ثم اعلم ظلّ الساعة كما تقدّم مثال ذلك: إن تسقط ميل الرخامة أكثر من [ارت]فاع الظلّ المستعمل فاعلم الساعة فما بقي خذ ظلّه المبسوط فهو ظلّ الساعة <المستعمل> في المائلة فإن كان ميل الرخامة أكثر من ارتفاع [الظ]لّ المستعمل فاعلم أنّ تلك الساعة لا يمكن وقوعها في الوجه الأرضي بل يمكن وقوعها في الوجه السمائي فإذا علّمت ظلّ [ال]ساعة في المائلة فخذ بقدره فتحة من مصطرة الأظلال المذكورة وضع رجله في المركز القائم على الزاوية وعلّم برجله <الأخرى> [تح]ته على خطّ الوتد ومدّه خطًّا مستقيمًا موازيًا للأفق بغير نهاية فإذا كُمِلت خطوط الأظلال لرأس المنقلبين فخذ فتحة بالبركار بقدر بعد تلك الساعة المفهوم من قسمة المصطرة المذكورة وضع رجله في المركز والأخرى حيث وقعت على خطّ الأفق إلى جهة الساعة في المنحرفة فأرخى منه شاقولًا فموضع تقاطع خيط الشاقول لخطّ ظلّ الساعة فهو موضع الساعة في المائلة فاجمع بين ساعات الجدي والسرطان ثم صل كلّ مدار منهما كما تقدّم وأمّا مدار الحمل فاستخرج بعد أفقه وظلّ السادسة ومدّ خطًّا مستقيمًا من الأفق إلى خطّ الساعة التي في المائلة واكتب على مدار اسم برجه وكذلك الساعات

واعلم أنّني استنبطتُ جدول هذه الطريقة من جداول البسيطات لجميع المائلات في الوجوه السمائية والأرضية منحرفة وقائمة[5] لجميع الأقطار والجهات ولم اعلم أنّني سُبِقتُ (؟) إلى استكمال شلوك هذه المسالك والله أعلم بذلك

فصل اعلم حتى كان ارتفاع الظلّ المستعمل في السطح القائم مثل ميل الرخامة فهي مظلمة في الوجهين فإن ارتفعت الشمس قليلًا استنار الوجه السمائي وأظلم

[5] MS السماويات والأرضيات منحرفات وقائمات

بقدر ظلّ الساعة مبسوطًا[16] أعني قسمة مسقط الحجر و <ضع> الرجل في مسقط الحجر والرجل الأخرى حيث وقعت على الخطّ موازي للأفق[17] فهو موضع الساعة في السطح المائل إن شاء اللّه تعالى فافهم تصب

<شكل> شكل المنحرفة عن خطّ نصف النهار ن مائلة إلى جهة المشرق ن لعرض لو شمال وهي تعمل من الزوال إلى آخر النهار

خطّ الأفق الغربي — مركز <الشخص> القائم على الزاوية — مركز <الشخص> المنكّس — طول الشخص الأوّل الذي وضع به — طول الشخص الثاني المنكّس لا ينتقل — مدار الجدي، مدار الاعتدال، مدار السرطان — سادسة، سابعة، … ، ثانية عشر — <عصر> — مسقط الحجر

البـــاب قيب في معرفة وضع المائلة من قبل [منحرفتها][1] والعمل في الوجه الذي يلي الأرض D:32r

[خذ] ظلّ [الساعة] <المستعمل الذي> [حفظته أ]وّلا [ل]تلك المائلة كما تقدّم وزده على ظلّ ميل الرخامة فما اجتمع اقسمه على قطر ظلّ ميل الرخامة فما حصل من القسمة[2] اضربه في بعد الساعة لتلك المنحرفة التي[3] تريد ميلها فما اجتمع فهو بعد تلك الساعة في المائلة فافهمه وإن لم تتعرّض (؟) [للحساب (؟)] فاستخرجه كما تقدّم قبله وإنّما أردنا الاختصار في هذا الباب وتيسيره على من يريد وضع المائلة وينبغي أن يُعلم بعد الأفق الأكثر بعدًا في المنحرفة أو <بعد> الساعة الأكثر بعدًا وتستخرج بعده في المائلة وتعلّم بعد الساعة في المنحرفة المخالفة فهو الأفق وخذ من تلك القسمة يب قسمًا فهو طول الشخص لتلك المائلة فاعمل منه مصطرة وما قصدنا بذلك الاحي (؟؟) لا محرح (؟؟) وضع الساعات عن (؟) الرخامة ثم خذ فتحة من تلك القسمة بقدر بعد الأفق الذي استخرجتَه وضع رجل البركار في طرف الرخامة والرجل الأخرى حيث وقعت على خطّ أفق المنحرفة فهو موضع مركز الشخص القائم على الزاوية[4]

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[16] مبسوط **MS** [17] الأفق **MS** [1] The barely legible word in the **MS** rather seems to be انحرافها as in Chapter 111. [2] من القسمة nearly deleted **MS** [3] الذي **MS** [4] الزاويا **MS**

فإذا علمت ظلّ تلك الساعة فخذ رخامة ومدّ فيها خطّ الأفق وخطّ وتد الأرض وقدر قامة فاقسمها يب قسمًا واعمل منها مصطرة وخذ من قسمة المصطرة بقدر ظلّ الساعة للمائلة بالبركار وضع رجله في المركز الأوّل ورجله الأخرى إلى جهة الأفق إن كان ظلّ فوق المركز أو إلى جهة الأرض إن كان الظلّ تحت المركز وعلّم برجله الأخرى علامة على خطّ الوتد ومدّها[12] خطوطًا موازية لخطّ الأفق فإذا كُمِلت هذه الخطوط وهي[13] خطوط أظلال الساعات

وأمّا أبعاد الساعات انظر إلى ظلّ الساعة إن كان فوق المركز فزده على ظلّ ميل الرخامة وإن كان تحته فخذ الفضل بينهما فما بقي احفظه أوّلًا ثم ضع رجل البركار في موضع تقاطع خطّ الأفق لخطّ الوتد وأدر برجله الأخرى نصف دائرة واقسمها قف وخذ من تلك القسمة قدر ميل الرخامة مبتدئاً من الأفق ومدّه خطًّا مستقيمًا إلى المركز الثاني بغير نهاية ثم خذ فتحة بقدر طول شخص المائلة وضع رجله في موضع تقاطع الأفق لخطّ الوتد وهو المركز الثاني وعلّم برجله <الأخرى> على خطّ الوتد ومدّه خطًّا موازيًا للأفق فموضع تقاطع هذا الخطّ للخطّ الشعاعي ضع رجل البركار عليه ورجله الؤخرى في المركز الثاني وانظر تلك الفتحة كم تكون من قسمة المصطرة فهو قطر ظلّ ميل الرخامة وهو أصل لجميع المائلات ثم خذ فتحة بقدر المحفوظ أوّلًا من قسمة مصطرة طول مري المائلة واقسم تلك الفتحة بقدر الأصل واعمل منه مصطرة ثانية وخذ من تلك القسمة بقدر بعد الساعة في المنحرفة وهو المفهوم في باب قط في عمل المنحرفة بفتحة بالبركار وضع رجله في تقاطع خطّ <ظلّ> الساعة للوتد وعلّم برجله الأخرى على خطّ ظلّ الساعة فهو موضع الساعة[14] في السطح المائل فافعل ذلك في السرطان والجدي واجمع الساعات وصل المدارات كما تصلها في المنحرفات فإن لم يكن بعد فهو <على> خطّ وتد الأرض وإن كان بعدها ليس له نهاية فلا[15] يمكن وقوعه في السطح المنحرف <...> فخذ من تلك القسمة

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[12] ومدهم MS [13] وهم MS [14] موضع الساعة] ميل الساعة MS [15] ولا MS

ثم كمّل المدارات بطريق سمت الساعات وأظلالها المنكوس كما شرحناه أوّلًا وصل كلّ مدار مع جنسه واستخرج سمت الزاوية لأحد الرخامتين لرأس المنقلبين وصل كلّ مدار إلى زاوية الرخامتين وكذلك الساعات إذا وقع بعضها في أحد الرخامتين والبعض في الرخامة الأخرى فصلهما إلى زاوية الرخامتين فإذا كُمِلت الساعات والمدارات وأردت طول الشخص فألزق الزاوية لجنب الحائط وجنبها الآخر في مركز الدائرة فمنه إلى الحائط فهو طول الشخص وأمّا مكانه فهو موضع خيط الشاقول على الأفق وأمّا وضع الموصولات المفتوحة والمغلوقة فما يعسر ذلك على من له صناعة في المنحرفات

<شكل> منحرفة عن خطّ نصف النهار مَ وهي الموصولة للمنحرفة الأخرى لعرض لوَ

الوجه الجنوبي الشرقي — خطّ الأفق الشرقي — طول الشخص لهذه المنحرفة — سرطان، ميزان، <جدي> — أولة (!)، ثانية، ... ، سادسة

هذه الورقة مكان الأرض لمنحرفة مَ — خطّ سعة مشرق السرطان — سمت أولة (!) السرطان — سمت ثانية السرطان[8] — سمت ثالثة السرطان — سمت رابعة السرطان — سمت خامسة[9] السرطان — سمت أولة (!) الميزان — سمت ثانية الجدي — سمت رابعة الجدي — سمت خامسة الجدي

البـــاب قيَا في معرفة وضع المائلة من قبل وضع منحرفتها[10] في الوجه الذي يلي السماء D:30v

اعلم ظلّ الساعة المستعمل[11] لذلك الانحراف وهو الذي حفظته أوّلًا لوقت الحاجة من باب قطَ ثم اعلم ارتفاع ذلك الظلّ من جدوله فما كان زده على ميل الرخامة إن كان سمت الساعة والرخامة في جهتين أو خذ الفضل بينهما إن كانا في جهة واحدة فإن كان الحاصل أكثر من صَ فاسقطه من قفَ فما بقي خذ ظلّه مبسوطًا فهو ظلّ تلك الساعة في المائلة فوق مركزها وإن كان المجموع أقلّ من صَ فخذ ظلّه مبسوطًا أيضًا فهو ظلّ الساعة في المائلة تحت المركز واعلم أنّ بعد مركز المائلة من الأفق بقدر ظلّ تمام ميل الرخامة

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[8] MS الميزان [9] MS ثالثة [10] MS انحرافها [11] MS مستعملة

أو الحائط وأرخى شاقولًا فموضع وقوع الخيط على الأفق فهو أفق الحمل وأمّا ظلّ الزوال للحمل فاقسم خطّ الزوال الذي في بسيط الأرض اثنا عشر قسمًا وخذ من تلك القسمة بقدر ظلّ منكوس سادسة الحمل <وانقل البركار بفتحته حتّى تضعه على موضع تقاطع الأفق لخطّ بعد الساعة السادسة والرجل الأخرى حيث وقعت هذا الخطّ وعلّم علامة فهو موضع الساعة السادسة للحمل> فصل منه إلى أفقه فهو مداره وكذلك إذا أردت أن تضع فيها جميع مدارات البروج فتضعها بظلّ الساعات منكوسًا وبسمتها

<شكل> منحرفة عن خطّ نصف النهار نَ وهي الموصولة للمنحرفة الأخرى لعرض لَو

الوجه الجنوبي الغربي — خطّ الأفق الغربي — مركز — طول الشخص لهذه المنحرفة — جدي، حمل، سرطان — سادسة، سابعة، ... ، ثانية عشر — عصر

هذه الورقة مكان الأرض لمنحرفة نَ — خطّ الزوال — خامسة الجدي — ٤، ٣، ٢، ١ <الجدي> — سابعة الميزان — سمت ثامنة السرطان — سمت تاسعة السرطان — سمت عاشرة السرطان — سمت حادية عشر السرطان — خطّ سعة مغرب السرطان

البـــاب قيَ في معرفة وضع الموصولة وهي على ثلاثة أشكال أحدها هذه D:30r

وهي التي تكون انحرافها مثل تمام المنحرفة الأخرى وهي[5] القائمة[6] على زاوية التربيع والثاني أن يكون انحرافها أكثر من تمام انحراف الأخرى وهي المفتوحة عن الزاوية والثالث أن يكون انحرافها أقلّ من تمام انحراف الأخرى وهي المغلوقة غير الزاوية

فإذا أردت وضع هذه الموصولة القائمة على الزاوية فافعل كما فعلت أوّلًا في المنحرفة وإنّما يكون طول شخصها من مركز الأولى إلى آخر الرخامة أعني آخر الرخامة الملتزقة للرخامة الأخرى المنحرفة[7] ويكون مركزه طول شخص الرخامة الموضوعة أوّلًا التي يقع فيها خطّ الساعة وتسمّى منحرفة بانفرادها فإذا اتّصلت برخامة أخرى سُمِيَت موصولة

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[5] وهما MS [6] القائمات MS [7] المنحرفة MS marg.

وأمّا طول الشخص القائم على بسيط الأرض فهو أن تقسم عرض الرخامة بقطر[3] ظلّ <تمام> ميلها وتأخذ من تلك القسمة يب فهو طوله

<شكل> قائمة على خطّ نصف النهار مائلة مشرق مه

خطّ الأفق الغربي — مركز الشخص المنكّس — مركز الشخص القائم على الزوايا — الشخص المنكّس — قوس العصر — سادسة، سابعة ... ثانية عسر — سرطان، ميزان ... قوس

<شكل> قائمة على خطّ نصف النهار مائلة مغرب مه درجة لعرض لو شمال

خطّ الأفق الشرقي — مركز الشخص المنكّس — مركز الشخص القائم على الزوايا — الشخص القائم على الزوايا — أولة (!)، ثانية ... سادسة — جدي، دلو ... جوزاء

.... في خطّ السادسة بين الرخامتين[4]

الباب قط في معرفة وضع المنحرفة من غير أن يُعلم الانحراف ولا طول الشخص ولا مركزه **D**:29v

وهو أن تدير دائرة <على> الأرض المصطحية ثم أخرج الجهات ومدّ خطّ نصف النهار وخطّ المشرق والمغرب ثم اعلم سمت الساعة وجهة سمتها من جدول البسيطة المذكورة وضع المصطرة على ذلك السمت وعلى مركز الدائرة وعلّم علامة على موضع <تقاطع> المصطرة للحائط واحفظها ثم أرخى عليه شاقولًا وعلّم في الأفق مكان الشاقول فهو موضع <علامة بعد> تلك الساعة فافهمه ثم اعلم ظلّ منكوس تلك الساعة لذلك لبرج من الجدول المذكور وضع رجل البركار في مركز الدائرة والأخرى على العلامة المحفوظة واقسم كلّ فتحة من هذه يب قسمًا متساويًا وخذ من تلك الفتحة بقدر ظلّ الساعة المنكوس واحفظه لوقت الحاجة للمائلات وانقل البركار بفتحته حتى تضعه على علامة بعد الساعة والرجل الأخرى حيث وقعت على خطّ الشاقول فهو مكان تلك الساعة فافعل ذلك للسرطان والجدي واجمع الساعات ثم اجمع كلّ مدار منهما وأمّا مدار الحمل فعلّم على موضع تقاطع خطّ المشرق والمغرب لأصل الرخامة

[3] بقطر] قطر **MS** [4] Written upside-down at bottom of **D**:29r

تقع في الأرض فخذ من مسقط حجر موضع المري إلى أصل الرخامة وهو طولها فاقسمه اثنا (!) عشر قسمًا متساويًا وخذ من تلك القسمة بقدر ظلّ الساعة السادسة مبسوطًا وضع رجل البركار في مسقط حجر رأس الشخص والأخرى حيث وقعت على خطّ مسقط الحجر فهو المطلوب

<شكل> شكل القائمة على خطّ نصف النهار لعرض لو شمال

وجه الرخامة الشرقي — مركز — خطّ الأفق — طول الشخص — نقطة مسقط[16] الحجر — الخطّ الموازي للأفق (مرّتان) — قوس أوّل وقت العصر — أولة، ثانية ... خامسة، سابعة ... ثانية عشر — سرطان، حمل \ ميزان، جدي

الباب قح في معرفة وضع القائمة على خطّ نصف النهار المائلة إلى جهة المشرق والمغرب مه

D:28v

فخذ فتحة بالبركار بقدر ظلّ الساعة في القائمة على نصف النهار الموضوعة قبل هذه واعلم وخذ ظلّه منكوسًا فهو ظلّ الساعة فوق المركز إن كان مجموعها[1] أكثر من ص وهو تحت المركز فزده على ظلّ ميل الرخامة وإن كان تحت المركز فانقص الأقلّ من الأكثر <...> الساعة في القائمة على خطّ نصف النهار فما اجتمع فهو بعد الساعة في المائلة واعلم أنّ هذه المائلة رخامتين أحدهما (!) متّصلة <بالأخرى> وأمّا مركز الشخص المنكّس فهو موضع نقطة طلوع الحمل وغروبه وأمّا طوله فهو قطر ظلّ تمام ميل الرخامة ||

D:29r

<...> درجة (؟؟) المشهورة بالمكنسة وذلك من قبل الرخامة القائمة على خطّ نصف النهار إذا أردت ذلك فخذ كم هو من أقسام قامتها المعلومة وانظر ما يحصّه من الارتفاع زده على ميل الرخامة وخذ <...> المركز إن <كان> مجموعهما أقلّ من ص فإن أردت البعد فانظر إن كان ظلّ الساعة فوق المركز فما بقي اقسمه على قطر ظلّ ميل[2] الرخامة فما حصل من القسمة اضربه في بعد الساعة واعلم أنّ بعد المركز من الأفق بقدر ظلّ تمام ميل الرخامة وكذا (؟) طوله فهو يب من مصطرة الوضع بالأخرى ويعمل من الطلوع إلى الغروب

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[16] MS سقط [1] MS مجموعهما [2] MS الميل

<شكل> شكل المكحل المخروط لعرض لو شمال

ساعات زمانية — طول الشخص المتحرّك — مجرّ الشخص المتحرّك وهو الأفق — خطّ الزوال — قوس العصر

البـــاب قز في معرفة وضع [القائمة على خطّ نصف النهار ....] D:31v

وذلك من قبل جدول البسيطة بالسمت والظلّ المنكوس وهو أن تمدّ خطّ الأفق وتر[خ]ى من أيّ موضع أردت شاقولًا[10] وهو خطّ الوتد وموضع الشخص <هو طقاتعه لخطّ الأفق> ثم ضع رجل البركار في موضع الشخص وأدر برجله الأخرى نصف دائرة واقسمها قف[11] وخذ من هذه القسمة[12] بقدر سمت الساعة مبتدئاً من موضع تقاطع خطّ الوتد لتلك الدائرة <فضع رجله على المركز> ورجله الأخرى حيث وقعت على الدائرة من جهة شمالك إن كان <السمت> شماليًا أو من جهة يمنك إن كان السمت يمانيًا[13] وضع عليه المصطرة وعلى موضع الشخص ومدّه خطًّا شعاعيًا ثم خذ فتحة بقدر طول الشخص الذي تريد وضع رجل البركار في موضع الشخص والرجل الأخرى حيث وقعت على خطّ الوتد فعلّم علامة واحفظها ومدّه خطًّا موازيًا للأفق ثم ضع رجل البركار في موضع العلامة المحفوظة والرجل الأخرى على موضع تقاطع الخطّ الشعاعي للخطّ الموازي للأفق وضعه بفتحته[14] <على> موضع الشخص ورجله الأخرى حيث وقعت على خطّ الأفق إلى جهة سمت الساعة فهو موضع بعد الساعة أرخى منه شاقولًا فهو خطّ بعد تلك الساعة ثم ضع رجل البركار موضع بعد الساعة والأخرى على العلامة المحفوظة ثم اقسم تلك الفتحة يب قسمًا وخذ من تلك القسمة بقدر ظلّ الساعة المنكوس وضع رجله في موضع بعد الساعة والأخرى حيث وقعت على خطّ البعد فهو موضع الساعة

فافعل ذلك لجميع الساعات لرأس البرج الذي يمكن أن يقع مداره في انتهاء الرخامة من جهة اليمين واليسار ثم صل المدارات وأمّا الساعة السادسة فهي[15]

[10] MS شاقول [11] MS ص [12] MS من هذالقسمة [13] MS يماني [14] MS بفتحة [15] MS فهم

D:31r

البـــاب قو في معرفة وضع ساعات المكحل [المصطحي][1]

[وه]و الذي يكون خرطه [سـ]و[اء ...] رأسـ[ه قسمًا] متساويًا لأصله كالأعمدة والأحقاق والعلب النقّالة المتحرّك عليها أشخاصها وهو أن تقسم دورها[2] ستّ قسمًا بقدر عدد البروج وتمدّ خطوطًا مستقيمة واكتب عليها أسماء البروج وإن شئت فاقسمها يب أقسام واكتب عليها اسم البرج وميله ثم خذ فتحة بالبركار بقدر طول ذلك المكحل واقسمه بقدر ظلّ الساعة الأكثر ظلًّا منكوسًا وقد يتّفق ذلك أن تكون سادسة السرطان في العروض الزائدة من الميل الأعظم ومتى كان العرض أقلّ من الميل الأعظم فقد يتّفق أن يكون ظلّ بعض الساعات منكوسًا أكثر من ظلّ سادسة برج آخر إن كان السرطان أو غيره وإذا فرغت من القسمة فخذ منها يب فهو طول الشخص المتحرّك على وجه الموضوع فاعمل من ذلك مصطرة ثم خذ من تلك المصطرة بقدر ظلّ الساعة المنكوس لرأس البرج الذي تريد وضع رجل البركار في أصل طرفي المدار واضرب برجله الأخرى على مدار ذلك البرج الذي أردت فهو موضع الساعات فافعل ذلك لجميع البروج وصل الساعات واكتب عليها عددها وإن أردت قوس العصر فاعمل بظلّه المنكوس لسائر البروج ونقّطها[3] نقطًا أو مدّها[4] خطوطًا فإن أردت وضع الارتفاع فاعمل بظلّ منكوس ذلك الارتفاع من درجةٍ إلى تسعة وثمانين واكتب عليها أعدادها فقد كُمِل الوضع

واعلم أنّ بعض الناس يدعها على الغاية ويكتب عليها آفاقية وهو خطاء وإنّما ينبغي أن يكون عليها تقريبًا للبلاد المسكونة فقط للشمس خاصّة أو تضع المدارات على نهاية غاية الشمس بتلك البلد وتكتب عليها عدد العرض الذي وضعت له وذلك محرّر[5] وكذلك وضع ساق الجرادة[6] مصطحية السطح[7] أعني تكون صفة لوح مصطحي[8] في نشرة أو آلة مصطحية[9] الجسم وتكون أشخاصها متحرّكة على الآلة

[1] Upper margin torn off. The final ب of the erroneous المصطحب is visible in the **MS**. [2] دورهما **MS** [3] ونقطهم **MS** [4] مدهما **MS** [5] محررا **MS** [6] الساق جرادة **MS** [7] المصطحة السطح **MS** [8] مصطحب **MS** [9] مصطحبة **MS**

فإذا كُمِل علامات جميع الساعات فضع رجل البركار في مركز علو الطاسة أو القبّة ورجله الأخرى على علامة تلك الساعة وانقل رجله التي على العلامة إلى أن تضعها على خطّ سمت تلك الساعة فهو موضع الساعة المطلوبة فاجمع الساعات والمدارات وكذلك قوس أوّل وقت العصر واكتب على كلّ منها[6] اسمه فقد كُمِل الوضع إن شاء الله تعالى

D:37r

البـــاب قه في وضع المصطرة التي[7] يؤخذ بها الارتفاع

وهي شكل ضلع[8] ذات الشعبتين وقسمتها كقسمة [هذا][9] الضلع[10]

بيانه أن تقسم وجه المصطرة س قسمًا متساويًا ثم تقسم ظهر المصطرة ل قسمًا وهو[11] قدر كه من [قسمة] وجهها وأقمها على قدر ما يكون الارتفاع وعلّم على طرف موضعها في الأرض وضع المصطرة عليه وعلى [رأس] المصطرة المقسومة ومدّه خطًّا مستقيمًا فهو موضع الخيط

واعلم أنّ نهاية إقامة هذه المصطرة على زوايا [قائمة] وذلك وقت يكون الارتفاع ص واعلم أنّ نهاية بسطها على الأرض وقت طلوع الشمس وغروبها

[ولو] أقمتَ عودًا أو غيره وفعلت ما ذكرناه وأفرضت قسمته تقديرًا وعلّمت الارتفاع في ذلك الوقت فذلك العود < ... >

وهذه المصطرة يُعلَم بها الارتفاع في كلّ وقت لكلّ عرض خلا وقت الزوال [إ]لّا أن يكون كبيرة مقسومة دقيقة دقيقة أو ثانية ثانية حتى يُعلَم منها الارتفاع وقت الزوال

<**شكل**> شكل المصطرة وقت يكون الارتفاع س

وجه المصطرة — ظهر المصطرة — بقية الارتفاع — صفة الخيط — صفة الأرض المستوية المبسوطة — علامة رأس المصطرة على بسيط الأرض

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[6] MS منهما [7] MS الذي [8] MS طلع [9] The beginning of each line is hidden by adhesive tape. [10] MS الطلع [11] MS وهي

وإن كان غير نصف دائرة مثل الطاسة أو الكشكول فقد استنبطنا له لوحًا[2] من خشب منجور وسعه مقسوم بنصفين وهو طول شخصه ثم وضعنا رجل البركار موضع طرف الشخص في ذلك اللّوح وأدرنا برجله ربع دائرة وقسمناها ص ثم قسمنا دور الكشكول شس ومددنا خطوط سموت الساعات من القسمة إلى مركز الطاسة فهو خطّ سمت الساعة ثم وضعنا الخشبة في وسط الطاسة وعلّمنا على موضع ارتفاع الساعة في الربع المقسوم وألزقنا الخشبة لخطّ السمت ونقلنا علامة ارتفاع الساعة إلى جسم الطاسة فهو موضع الساعة فإذا كملت جميع الساعات فصلها[3] ثم صل المدارات وأحسن وضعها أن يكون اثنا عشر مدار ليُعلَم منها إخراج الجهات واكتب على المدارات أسماء البروج فقد كُمِل الوضع

ولا يمكن التشكيل في الورق لإنّه مجوَّف فمن أراد أن يضعه فليتأمّل ما ذكرناه إن شاء اللّه تعالى وقد يوضع تارّة ثابتًا وتارّة نقّالًا واعلم أنّ طول الشخص هو من مركز الخشبة إلى نصفها

الباب قد في معرفة وضع الطاسة على ظهرها وهي ساعات القبّة على ظهرها D:37v

وهو أن تقسم دور الطاسة أو القبّة شس قسمًا متساويًا وتمدّها[4] خطوطًا إلى نقطة مركز علو الطاسة أو القبّة فهي[5] خطوط السموت وإن كانوا ثابتًا فاخراج الجهات وإن كانوا متحرّكين فلا يحتاج إلى اخراج الجهات ثم ضع المصطرة على مركز علو القبّة وافرض شخصًا وضعه على المصطرة واحسب سمك المصطرة من طول الشخص ثم ضع خيطًا على طرف ذلك الشخص بعد أن تقسم المصطرة بقدر طول القامة وضع الخيط على قدر ظلّ الساعة الذي تريد فإن أمكن وقوع الخيط على القبّة وإلّا اصغر القامة فلا تزال تنقص القامة أو تزيدها حتى يقع ظلّ تلك الساعة على طرف القبّة ثم تضع الخيط على الساعة الثانية والثالثة والرابعة والخامسة والسادسة وعلّم في القبّة على وقوع الخيط على سمت واحد

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[2] لوح MS [3] فصلهما MS [4] وتمدهم MS [5] فهم MS

جدول البسيطة لعرض [لو] *				
جدي		سرطان		
ظل	بعد	ظل	بعد	
ﮒ ﮒ	س ﮒ	نو ﮒ	مه ل	ا
يه ل	كز مه	مه ه	كا ﮒ	ب
كا ل	يز م	ما م	يجك	ج
لجك	ط لب	م ﮒ	ز ل	د
كد ﮒ	د ﮒ	لط ك	ج لز	ه
كد يد	ﮒ ﮒ	لط ط	ﮒ ﮒ	و
يح ل	ك ل	مب ﮒ	يج م	عصر
بعد عصر الحمل يح لط ظل عصر الحمل لح لد		ظل سادسة الحمل لح لد بعد المركز عن الأفق م ل		

صورة الجدول وهو مثل جدول ** المنحرفات والوضع به كوضع المائلات † وهو جدول غريب جدًّا يغني عن جدول البسيطة والله تعالى أعلم

* **MS** om. ** **MS** جدوال † **MS** المنحرفات

البـــاب قجَ في معرفة وضع ساعات الجرن لا يخلو[1] إمّا أن يكون الجرن نصف دائرة أو غير ذلك **D**:37v

فإن كان نصف دائرة فأصلح علوه ليكون أفقًا صحيحًا ثم اقسم نصف دائرة أعني جوفه قف وضع رجل البركار في وسط الجرن ورجله الأخرى على ارتفاع تلك الساعة بعد أن تقسم دور علوه شس قسمًا وأرخى شاقولًا من تلك القسمة بقدر سمت الساعة مبتدئاً من نقطة المشرق ومدّ خطًّا إلى مركز الجرن وضع رجله التي على ارتفاع الساعة على خطّ سمت الساعة وعلّم الساعات جميعها وصلها واكتب عليها أعدادها ثم صل المدارات واكتب عليها أسماء البروج

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[1] **MS** يخلوا

بقي خذ جذره فهو بعد المركز من الأفق ولم نذكر في كتابنا هذا الجذر إلّا في هذا الموضع[7] فإنّ مائلة ص ظلّ تمام ميلها ليس له نهاية فتخيّلنا عليه من جهة الضرب والجذر وإن أردت أن لا تتعرّض لا لضرب ولا لجذر فتخطّ خطًّا مستقيمًا وتقسمه بالبركار بقدر بعد الساعة وتضع عليه جنب[8] الزاوية وتمدّ على جنبها الآخر خطًّا بغير نهاية ثم تأخذ فتحة بالبركار من تلك القسمة بقدر ظلّ الساعة مبسوطًا وتضع رجل البركار في طرف الخطّ الأوّل والرجل الأخرى حيث وقعت على الخطّ الثاني فعلّم علامة ثم ضع رجل البركار في تلك العلامة والرجل الأخرى في موضع تقاطع الخطّين فما حصل من تلك الفتحة من القسمة فهو بعد المركز من الأفق المائلة ولم أعلم أحدًا[9] ذكر هذه الطريقة فإنّ الشيخ أبو علي المرّاكشي رحمة اللّه عليه ذكر بكلّ مائلة طريق جعل المائلات من فط إلى مه وطريق وضعها بالبعد والظلّ المستعمل والمرتفعات من آ إلى مه وطريق وضعها بالسمت والظلّ

وقد شُكِّل وبعضها في الوجه السمائي[10] ولم نتعرّض إلى الوجه الأرضي وطريقتنا هذه فتح اللّه بها البعض في اليقظة والبعض في المنام

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[7] MS هذالموضع [8] MS جيب [9] MS أحد [10] MS السمالي

البـــاب قب في معرفة البسيطة من غير أن تتعرّض[1] إلى وضع المصطرة على سمت الساعات وأظلالهم المبسوطة D:56v

وذلك بطريقة [الماء]لات فإنّ البسيطة هي القائمة على خطّ المشرق والمغرب مائلة ص إلى جهة الشمال

إذا أردت ذلك فاستخرج جدولها ومعرفة [اس]تخراجه أن تعلّم بعد الساعة وظلّها المستعمل في القائمة على خطّ المشرق في الوجه الشمالي أو الوجه الجنوبي ثم تعلم ارتفاع ذلك الظلّ [الم]ستعمل وتأخذ ظلّه منكوسًا فإنّك أن زدته على ميل الرخامة أو أنقصته من ميل الرخامة وأخدت ظلّ ما بقي <مبسوطًا وإذا كان ميل الرخامة ص > فيحصل[2] الظلّ المنكوس فلذلك ذكرناه قبل أن تتعرّض إلى ميل الرخامة فما كان الظلّ المنكوس هو ظلّ تلك الساعة <المستعمل> في البسيطة ثم انظر إن كان سمت الساعة شمالي فظلّها تحت المركز وإن كان سمتها جنوبي فظلّها فوق المركز فاحفظه وما ذكرنا السمت هنا إلّا لكون إنّ ميلها ص وما تعلّم فوقه من تحته إلّا من جهة السمت لهذه المائلة خاصّة

وأمّا البعد فاقسم ظلّ الساعة الذي حفظته على[3] قطر ظلّ المائلة[4] وهو يب فما حصل اضربه في بعد الساعة في القائمة على خطّ المشرق فما اجتمع فهو بعد الساعة في البسيطة فإن أردت أن تضع سائر المائلات كما تضع المنحرفات فانظر إلى ظلّ الساعة <المستعمل> إن كان فوق المركز فانقصه من ظلّ تمام ميل الرخامة وإن كان تحته فزده على ظلّ تمام ميل الرخامة فما حصل فهو ظلّ تلك الساعة من الأفق والبعد على حالته فصوّره جدولًا وضع منه كما تضع المنحرفات

واعلم أنّ بعد المركز من الأفق بقدر ظلّ تمام ميل الرخامة فإن أردت بعد المركز من الأفق فاضرب بعد أولى[5] الجدي في مثله واضرب ظلّها المبسوط في مثله وانقص ما حصل من ضرب البعد من حاصل ضرب الظلّ[6] المبسوط فما

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[1] اتعرض MS [2] فيحصل] حصل MS [3] على] من جهة MS [4] قطر ظلّ المائلة] قطر الظلّ للمائلة MS [5] أولة MS [6] ظلّ MS

فقد وضعت قوس العصر فلزمنا أن نستخرج لقوس العصر ارتفاعًا وسمته وجهة سمته للبروج المذكورة في العروض المفروضة وتجدول لها[11] جدولًا ونشكّل كلّ قوس من المذكورين ونكتب[12] عرض البلد الذي حسبنا[13] له على كلّ قوس منهما[14] وعلى الجدول لنبيّنه ونهوّنه لمن يريد الوضع إن شاء في الرخامات أو الآلات أو ثابتًا بسيطًا أو قائمًا

جدول لوضع قوس العصر لبلد لا عرض له من البسيطة والقائمة والآلات

سرطان		نصف الثور		حمل		نصف العقرب		جدي	
سمت	ظل	سمت	ظل	سمت	ظل	سمت	ظل	سمت	ظل
شمال كا كو *	يز يه	شمال ك نا	يه لب	د د	يب د	ك نا	يه لب	كو	يز يه

جدول لوضع قوس العصر لعرض يب في البسيطة والقائمة والآلات

سرطان		درجة المسامتة		حمل		درجة نظير المسامتة		جدي	
سمت	ظل	سمت	ظل	سمت	ظل	سمت	ظل	سمت	ظل
شمال كا د	يد كج	شمال ه د	يب د	جنوب ط نب	يد لج	كج مد	يز كا	له مج	ك ند

* كو د كا with د crossed out **MS**

<شكل> أشكال أقواس العصر للعروض التي هو أقلّ من الميل الأعظم

طول الشخص لبلد لا عرض له — خطّ الزوال لبلد لا عرض له — سرطان، نظير درجة المسامتة، حمل، درجة المسامتة، جدي طول الشخص لعرض يب — خطّ الزوال لعرض يب — قوس العصر لعرض يب — سرطان، حمل، نظير درجة المسامتة، جدي

[11] لهما **MS** [12] تكتب **MS** [13] حسبت **MS** [14] منها **MS**

D:56r **البـــاب قاَ في معرفة وضع قوس العصر في الرخامات والآلات**

اعلم أنّ بعض الناس وضع أصطرلابات وفيها صفائح كثير ونُقِش في كلّ صفيحة قوس العصر لعروض كثير ولمّا وفقتَ على الصفائح فوجدتَها غلطًا على قوس العصر فردّد به (؟) إلى الصواب وكشّط[1] النقش وأثبت ما ذكرتُه لك (؟)[2]

وقد سمعتُ من بعض الفضلاء في هذا الفنّ أنّه وفق على نسخة من نسخ الشيخ الفاضل أبو علي المرّاكشي وفيها قوس العصر مرسوم لبلد لا عرض له وهو مقوّس إلى جهة المشرق قوسًا واحدًا بمركز واحد فعلينا لعلّ أن يكون ذلك من النسّاخ كما قيل وما إنّه الأخبار إلّا روايتها لأنّ الشيخ أبو علي ما شكّله هذه فما بنسخة الآلات رسمه

فاحتجت أن اذكر ذلك لمن يريد الوضع وهو إذا كان عرض البلد أكثر من الميل الأعظم فإنّ قوس العصر كالعادة قوسًا واحدًا وله مركز واحد وهو نسبة إلى جهة واحدة وإن كان العرض أقلّ من الميل الأعظم كان قوس العصر قوسين كلّ منهما له مركز تارّة يكون جهة تقويسة لجهة واحدة وتارّة يكون لجهتين

فإذا أردت وضع ذلك في الرخامات فضع مركز الشخص الذي تريد وأدر في مركزه دائرة واقسمها شس قسمًا وخذ من تلك القسمة بقدر سمت العصر مبتدئاً من خطّ المشرق لرأس المنقلبين ولدرجة المسامتة واعلم سمت عصر الدرجة التي[3] بين درجة المسامتة والجدي[4] واعلم أظلالها وافعل كما فعلت في ساعات البسيطة واجمع الثلاث علامات وهي[5] علامات الجدي والميزان وما بينهما من درج البروج فهي[6] نظير درجة المسامتة فهو القوس الأوّل ثم اجمع الثلاث علامات الأخرى[7] وهي[8] علامات الحمل ودرجة المسامتة، وهي التي يكون ارتفاع عصرها مه درجة، <وعلامة السرطان> فاجمعها[9] مع <علامة> نظير درجة المسامتة وعلّم على الساعات أو على المقنطرات واجمعها[10] قوسًا واحدًا ثم اجمع الثلاث علامات الآخر قوسًا واحدًا

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[1] فكشط MS [2] له MS [3] الذي MS [4] والاعتدال] والجدي MS [5] وهم MS [6] فهم MS
[7] الآخر MS [8] وهم MS [9] فاجمعهما MS [10] واجمعهما MS

لأنّها درج فوق درج ومتى شكّلناه في الورق جاء مثل شكل المكنسة الآتي شكلها فلا نعيد تشكيله هنا شيئًا لأنّ التشكيل بگهير (؟) الواضع واعلم أنّ الدرج تارّة يكون سواء وبسطاتها[3] غير سواء وتارّة يكون الدرج والبسطات غير سواء ولا يمكن تساويها[4] لأنّ الساعة الأولى أكثر ظلًّا من الساعة الثانية والساعة الثانية أكثر ظلًّا من الساعة الثالثة وعلى هذا القياس وإن كانت متحرّكة فيحتاج أن تضع المدارات

البـــاب قَ في معرفة وضع ساعات ساق الجرادة المركّبة[5] ساعاتها على الارتفاع لرأس[6] البروج ولأيّ عرض أردت D:55v

وذلك أن تقسم عرضها بستّة أقسام متساوية واجمعها[7] على نقطة واحدة فهي[8] خطوط المدارات ثم أدر ربع دائرة مقسومة صَ وضع المصطرة على ارتفاع كلّ ساعة وعلى مركز الربع وهو مركز الشخص وعلّم على تقاطع المصطرة للمدار فإذا كُمِلت الساعات فاكتب أعدادها وأمّا طول الشخص فأقم مسقط حجر السادسة لأيّ برج أردت موضع تقاطع الخيط للأفق عليه ثم خذ فتحة بالبركار بقدر يبَ وضع رجله على العلامة والأخرى حيث وقعت على خطّ الوتد فهو طول شخص تلك الساق جرادة[9] وهو ثابت غير متحرّك

<شكل> شكل ساق الجرادة المركّبة[10] على ارتفاع الساعات لعرض لوَ[11]

المركز — خطّ الأفق — مسقط[12] الحجر — (أسماء البروج)

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[3] MS بسطاطهم !!! [4] MS تساوهما [5] MS **الساق جرادة المركب** [6] MS رؤس [7] MS واجمعهما
[8] MS فهم [9] In classical Arabic we would expect ساق الجرادة تلك [10] MS الساق جرادة مركب
[11] لعرض لوَ written in a ‘degenerate’ decorative Kufic: the letter ر is written as a ن; the final tail of the ض has been extended upwards in both directions so as to resemble again a ن; moreover there is a superfluous dot over it. the و looks like an undotted ف, with a dot over the final tail as on that of the ض [12] MS مسقوط

D:55r (left)

البـــاب صح في معرفة وضع ساق الجرادة[6] المركّبة على البروج لعرض مخصوص لأيّ بلد أردت

وهو أن تتّخذ لوحًا[7] مصطحيًا[8] وتقسمه يب قسمًا ومدّها[9] خطوطًا واكتب عليها[10] أسماء البروج واقسم أحد الخطوط بقدر ظلّ منكوس نهاية الغاية بتلك البلد ثم خذ تلك القسمة يب فهو طول الشخص واعمل منه مصطرة يؤخذ م[نها] بقدر ظلّ منكوس الساعات لرأس البرج الأكبر ظلًّا وضع رجله في المركز والأخرى حيث وقعت على خطّ الوتد واعلم أنّ كلّ مدار له قامة ⌈ واك[تب عليه عر]ض البلد ⌉[11]

<شكل> شكل ساق الجرادة[12] المركّبة على البروج لعرض لو

المركز — خطّ الأفق — طول الشخص — لعرض لو — (أسماء البروج)

D:55v

البـــاب صط في معرفة وضع ساعات السلّم المدرّج الثابت على بسيط الأرض

وهو الذي كلّما مضي من النهار ساعة نزل ظلّ الشخص درجة وكلّما بقي من النهار ساعة طلع ظلّه درجة وذلك أن تتّخذ رخامة مصطحية يكون سمكها نسبة واحدة أو يكون علو شبيه بها بقدر طول الشخص الذي تريد ثم تقسم ذلك الشخص يب قسمًا متساويًا ثم تستخرج خطّ نصف النهار في أرض مستوية تعلّم على موضع الشخص ثم تمدّ خطًّا سمت الخامسة من جهة المغرب وسمت الرابعة من جهة المشرق لرأس المنقلبين وتستخرج أظلالها [ا]تلك[1] الساعات وتمدّ خطًّا كما تضع ساعات البسيطة واعلم أنّ القامة هي قدر ما بين طرف الشخص وسمك الرخامة الأولى ثم ضع رخامة ثانية فوق الأولى بعد أن تُخرِج سمت الرابعة والثامنة وتفعل كما فعلت أوّلًا من جهة المشرق والمغرب واعلم أنّ كلّما وضعتَ رخامة فوق الأخرى نقص طول المركّب فيحتاج الواضع أن يكون له نظر كافي فإنّ الحاضر يرا ما لا يراه الغائب ولا يمكن تشكيلها[2] في الورق

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[6] الساق جرادة MS [7] لوح MS [8] مصطحب MS [9] ومدهما MS [10] عليهم MS [11] ⌈…⌉ marg. MS [12] الساق جرادة MS [1] Beginning of the line hidden under adhesive tape. [2] تشكيلهما MS

الربع ص وضع المصطرة على ارتفاع تلك الساعة مبتدئاً من الأفق من قسمة الربع المذكور وعلى مدخل الشعاع فهو موضع تقاطع المصطرة للمدار المطلوب فعلّم عليه علامة فهو موضع الساعة فافعل ذلك للمدارات التي[9] تريد فإذا كملت علامات الساعات فاجمعها[10] واكتب عليها أعدادها واكتب على كلّ مدار اسم برجيه

ومن الناس مَن يضعه من الناحيتين ويكون مدخل الشعاع موضع الأفق حتى تكون ساعات نصف النهار الأوّل متّصلة بساعات نصف النهار الثاني

فقد كُمِل وضع الدملج إن شاء الله تعالى

<**شكل**> شكل الدملج لعرض لو

مدخل الشعاع — مسقط حجر الشعاع — قوس الارتفاع لسائر الساعات لجميع البروج — سرطان، حمل، جدي

<**ملاحظة**> هذا القوس هو ثلث دائرة الدملج تارّة يكون موضوعًا لستّ ساعات آخر (!) وتارّة ليس يكون فيه[11] وضع على هذه الصورة

الباب صز في معرفة وضع ساق الجرادة[1] المركّبة على الغاية لعرض مخصوص لأيّ بلد أردت D:55r (right)

وهو أن تتّخذ لوحًا[2] مصطحيًا[3] وتقسمه بقدر ظلّ منكوس نهاية غاية تلك البلد أقسامًا متساوية واكتب عليها عدد الغايات بعد أن تمدّها[4] خطوطًا مستقيمة ثمّ اقسم أحد الخطوط بقدر نهاية ظلّ منكوس بتلك البلد وافعل ما تقدّم واجمع علامات الساعات ثم اكتب عليه عدد عرض البلد الذي وُضِع له فافهم تصب إن شاء الله تعالى

<**شكل**> شكل ساق الجرادة[5] المركّبة على الغاية لعرض لو

المركز — خطّ الأفق — طول الشخص — لعرض لو

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[9] MS الذي [10] MS فاجمعهما [11] ليس is written above يكون فيه MS [1] MS الساق جرادة
[2] MS لوح [3] MS مصطحب [4] MS تمدهم [5] MS الساق جرادة

عُلبةٍ وقد يُرسم على حُقّ وتكتب عليه عدد عرض البلد الذي وضع له فتارّة يُوضع على البروج وتارّة على الغاية لبلد معلوم العرض

واعلم أنّ هذا الشكل لا يشكّل في الورق فإنّ الورق لوح مبسوط مصطحي[2] والعمود مدوّر فلا يمكن تشكيله فإذا شكّلناها في الورق جأت منحرفة بمداراتها فمن أراد وضعه يفهم ما ذكرناه

البـــاب صه في معرفة وضع الميزان الفزاري **D**:54r

وهو أن تتّخذ خشب لها سمك من الأربع جوانب صحيحة البدن ثم تقسمها بين قامتيها بأيّ قدر شئت وأحسنه[3] أن يكون مقسومًا[4] قمد ثم تكتب عليها أعدادها وتكون قامتها الواحدة مقسومة يب قسمًا وقد يُوضع على جنبها ساعات آفاقية ليس لها صحّة وإنّما ينبغي أن تكتب على جنبها ظلّ الزوال لسائر البروج في ذلك العرض وقد تُعمَل على جنبها ساعات مخصوصة للعروض المسكونة وهي[5] السبع الأقاليم وقد تقدّم الوضع في تلك الساعات وهي تقريب جيّد ولم نذكر هذا[6] الميزان إلّا لكونه[7] آلة عتيقة وهي آلة ظلّية والأظلال مذكورة في الجداول المتقدّمة ممّا (؟) فرضنا فيها

<**شكل**> شكل الميزان الفزاري

البـــاب صو في معرفة وضع ساعات الدملج **D**:54v

وهو الذي يكون دائرة كاملة صحيحة الدور ثم اقسم دوره شس قسمًا متساويًا وتأخذ من تلك القسمة ل مبتدئاً من العلاقة فهو موضع الخرم الذي يدخل منه الشعاع عند أخذ الارتفاع ثم علّم على ل[8] من الجهة الأخرى المقابلة للخرم وهو موضع الأفق ثم ضع رجل البركار في موضع مدخل الشعاع ورجله الأخرى موضع الأفق وأدر ربع دائرة متّصلت بمسقط حجر الشعاع واقسم ذلك

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[2] مصطحب **MS** [3] وأحسنها **MS** [4] مقسومة **MS** [5] وهما **MS** [6] هذه **MS** [7] لكونها **MS**
[8] Hole **MS** (but ‌ا is visible)

كُمِل وضع العمود

وإن لم يوضع على هذا الشروط المذكورة فالوضع سقيم وقد وجدتُ وضع الأعمدة على خلاف ما ذكرناه وهو سقيم ليس بصحيح ومن أراد السقيم من الصحيح فليتأمّل الساعات طرفي النهار قريب طلوع[12] الشمس أو قريب غروبها فإنّ الوضع في ذلك الوقت يخجل واضعه إذا كان الوضع سقيم ويتبصر إذا كان صحيح وبعض الناس في وضعه ضاعون[13] ليس معهم طريق يوصّل إلى الصواب وقد عاينته بأعمدة بالقاهرة وهو سقيم لا سيّما إذا أمكن النظر إلى ظلّ الشخص طرفي النهار فإنّه يخطئ قريب ساعة

فإن كان العمود مخروطًا فافعل ما تقدّم في وضع المخروطات بعد أن تعلّم موضع ظلّ الساعات كما عرفتُك في ميل الخراطة وثبّت الظلّ على خطّ البعد في العمود وإن كان غليظه لفوق فتعلّم بعد الساعة إن كان يمكن وقوعها على العمود أم لا كما تقدّم في المخروطات

<شكل>

وجه العمود وساعاته من طلوع الشمس إلى غروبها — ظهر العمود وساعاته من الزوال إلى غروب الشمس — دائرة إخراج الجهات — خطّ نصف النهار — خطّ سعة مشرق السرطان — علامة خطّ الزوال في العمود — علامة أفق السرطان في العمود — مركز الشخص — طول المري — لعرض لو

البـــاب صد في معرفة وضع ساعات الأعمدة النقّالة وأشخاصها المتحرّكة يُعلم منها الماضي[1] فإخراج الجهات إذا أردت ذلك فاقسم دور العمود شس قسمًا ومدّ خطّ نصف النهار وخطّ المشرق ثم علّم على سمت تلك الساعة في جهتها وأرخى على تلك العلامة شاقولًا وعلّم على الشاقول بقدر ظلّ الساعة منكوس من قسمة طول الشخص المتحرّك فإذا علّمت جميع الساعات فاجمعها مدارًا واكتب على كلّ مدار اسم برجه ثم افعل ذلك لرأس المنقلبين وصل الساعات خطوطًا وافرض لموضع الشخص مكان في العمود على الأفق وقد رسموا ذلك على وجه D:54r

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[12] MS طوع [13] MS ضاعين [1] MS ماض

الدائرة وعلى سعة مشرق أحد المنقلبين وعلّم على تقاطع جنب المصطرة لأصل العمود واحفظه ثم ضع المصطرة على المركز وعلى خطّ نصف النهار وعلّم على تقاطع لأصل العمود أيضًا واحفظه فإن لم يصل إلى أصل العمود فأدر دائرة غير تلك الدائرة ولا تزال تدير دائرة بعد دائرة حتى يقاطع جنب المصطرة أصل العمود بحسب أن يكون كأنّه اسمه لا يكون ممكنًا فيه ولا خارجًا عنه فاحفظ تلك العلامتين وهي[10] علامة سعة المشرق وعلامة خطّ نصف النهار فاقسم ما بين العلامتين بنصفين في أصل العمود على خطّ صحيح فهو موضع مسقط حجر أصل الشخص أرخى منه شاقولًا موافق العمود فهو موضع الشخص ثم خذ فتحة بالبركار من مركز الدائرة إلى علامة مسقط الحجر فهو طول الشخص الذي يوضَع على الأفق ثم ضع مصطرة على مركز تلك الدائرة وعلى سمت أيّ ساعة أردت وعلّم على تقاطع جنب المصطرة لأصل العمود فهو موضع مسقط حجر ذلك السمت أرخى عليه شاقولًا فهو خطّ بعد الساعة ثم خذ فتحة من مركز الدائرة إلى علامة بعد خطّ السمت الذي في أصل العمود واقسم تلك الفتحة $\overline{\text{يب}}$ قسمًا واعمل منها قامات وخذ من تلك القامات بقدر ظلّ الساعة منكوس وضع رجل البركار في موضع تقاطع خطّ السمت للأفق والرجل الأخرى على خطّ بعد الساعة وعلّم علامة فهو موضع الساعة على وجه العمود فافعل ذلك للمنقلبين واجمع المدارات وصل الساعات واكتب عليها أعدادها وأسماء البروج

وهذه الساعات ستّة منها تعمل من أوّل النهار إلى الزوال تكون موضوعة في العمود[11] من جهة المشرق وستّة آخر تعمل من الزوال إلى آخر النهار تكون في العمود من جهة المغرب وإن شئت فاعمل في هذه الستّة قوس عصر وإن شئت أن تضع خطوط السموت فمدّ خطوط الأبعاد عشرة عشرة أو غير ذلك وإن شئت أن تضع المقنطرات فتقسم الخطّ يمرّ بمركز الدائرة وخطّ البعد المُعلَّم في أصل العمود $\overline{\text{يب}}$ قسمًا وخذ من تلك القسمة بقدر الظلّ المنكوس لعدد المقنطرة إن شئت ستّة ستّة أو غير ذلك واكتب على السموت والمقنطرات أعدادها فقد

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[10] وهما MS [11] الحمود MS

العصر فإن شئت أن تخرق مكان القوس أم لا واعلم أنّ موضع مركز الشخص هو موضع تقاطع مدار ص للأفق

ولا ينبغي أن يوضع شكل آفاقي غير قوس العصر إمّا مبسوطًا أو منكوسًا لمن الناس مَن يقول إنّ الساعات الستّة وساعات العضادة والبسيطة التي تعلّق على الغاية التي هي لبسيطة بلد لا عرض له وساعات الربع المجيّب التي[3] قدروها لكلّ يه ساعة وإنّ الجداول المكتوب عليها ارتفاع الساعات الآفاقية على التحرير وكلّ ذلك تقريبًا للشمس خاصّة في البلا[د المسكو]نة[4] خاصّة وكلّ من أخذ شكلًا من هؤلاء المذكورة وأضاف[5] إليه شكل آخر من آلة أخرى تامّة الأعمال فقد أخطأ فإنّ الآلة تامّة الأبواب[6] ما يحتاج إلى غيرها وكذلك الحساب إذا أضافه لآلة من الآلات فقد أخطأ

واعلم أنّ هذا العلم على ثلاثة أقسام : حساب وهندسة وآلات فكلّ منها منفرد أبوابه[7] فمتى أشرك بين بابين (؟)[8] منها[9] فقد نقص كلّ منهما فالحساب لا يشاركه هندسة ولا آلة والهندسة لا يشاركها إلّا شيء يسير من الحساب مثل أزمان الساعات في بعض الوضعيات والآلات المخصوصة كذلك يشاركها شيء من الحساب مثل درجة الشمس وتعديلها والآلات الآفاقية مثل أزمان الساعات والمطالع البلدية وما أشبه ذلك والحساب لا يشاركه شيء أصلًا فكذلك كان أشرف وأحسن من هذه الثلاثة أقسام

<شكل> شكل العصر الآفاقي لسائر العروض

مركز — طول المري — خطّ الزوال آفاقي — قوس العصر

الباب صح في معرفة وضع ساعات الأعمدة الثابتة كأعمدة الجوامع والمساجد وغيرها D:53v

وهو أن تدير دائرة في الأرض وتخرج الجهات وتضع المصطرة على مركز تلك

[3] MS الذي [4] Smudged MS [5] smudged MS أضاف [6] MS الآلة التامة الأبواب [7] MS باباه [8] MS أمان ! [9] MS منهما !

البادهنج

ولم أطلع على هذه الطريقة ممّن تقدّم من الفضلاء ولا أعلم أحدًا ذكرها فمن أراد التحرير في ذلك فليفعل ذلك كما[19] بيّنّاه وشرحناه فافهم تصب

<شكل> <شكل البادهنج>

محلّة البادهنج لعرض لَ وهو ظهرة[20] المسدود — مسدود — وجه البادهنج وهو مفتوح — مفتوح — جنوب، مشرق، شمال، مغرب — أوّل الطياب — آخر الطياب — أوّل المريس — وسط المريس — آخر المريس

البـــاب صبَ في معرفة وضع قوس العصر الآفاقي متحرّكًا وشخصه ثابت فيه **D**:53r

وقد وضعناه في لوح من خشب إذا أردت ذلك فاتّخذ لوحًا[1] مصطحي[2] واقسم عرضه بقدر غاية الارتفاع من درجة إلى تسعين وخطّ خطوط مدارات الغاية إن شئت عشرة عشرة أو خمسة خمسة أو غير ذلك وأحسنه درجة درجة إن كان فيه كثر لأنّه إذا كان درجة درجة كان كامل المدارات ثم اكتب على كلّ مدار عدده واقسم أحد المدارات ثلاثون (!) قسمًا ثم خذ من تلك القسمة قسمًا واحدًا فهو طول القامة والاختيار إليك إن شئت أكثر من لَ أو أقلّ وإنّما إذا كانت القسمة أكثر من ذلك كان العمل تدخل فيها من غاية ذلك الظلّ المنكوس الذي قسمنا به

ثم خذ بقدر طول القامة وضع رجل البركار في الأفق على موضع مدار صَ ورجله الأخرى حيث وقعت على خطّ الوتد ومدّه خطًّا مستقيمًا موازيًا للأفق ثم ضع رجل البركار في موضع تقاطع الوتد لخطّ مدار صَ ورجله الأخرى على موضع تقاطع كلّ مدار واقسم تلك الفتحة يبَ قسمًا وتأخذ من تلك القسمة بقدر ظلّ عصر ذلك المدار منكوس وضع رجله في موضع تقاطع المدار للأفق واضرب برجله الأخرى على خطّ المدار ولا تزال تفعل كذلك حتى تُكمل علامات المدارات ثم اجمع العلامات قوسًا واحدًا إمّا نقطًا أو غيرها فهو قوس

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[19] فيما **MS** [20] Probably with the same meaning as ظهارة (‘outside, reverse side’). [1] لوح **MS**
[2] مصطحب **MS**

D:52v **البـــاب صا في معرفة وضع مَحِلّة الباذَهَنج وأسمائه وقدر الهواء الطياب وقدر الهواء المفسود من قسمة دائرة الأفق لذلك العرض**

أمّا أسماؤه[8] فهي[9] أربعة : فراتي ومجنّح وكلّي وعادلي فأمّا الفراتي فهو القائم على سطح مستقيم وأمّا المجنّح فهو [ا]لقائم[10] على سطح مجنّحًا[11] كأجنحة الطير وأمّا الكلّي فهو السطح المائل وأمّا العادلي فهو الذي يكون بجنب حائط

فإذا أردت وضعه فه[و] أن تدير دائرة كاملة وتربّعها وتمدّ خطًّا من سعة مشرق الجدي إلى سعة مغرب السرطان بتلك البلد فهو محلّة البادهنج في [ال]بلاد البعيدة عن البحر المالح <وفي البلاد القريبة من البحر> مثل سكندرية (!) ودمياط وعيذاب[12] وجدّة وما أشبه ذلك < ... >

فإذا عملتَ محلّة البادهنج كما [تق]دّم فمدّ خطًّا من نقطة المشرق إلى ضعف سعة مشرق الجدي وهو الموضع المسدود ثم مدّ خطًّا من نقطة المغرب إلى ضعف سعة مغرب السرطان وهو الموضع المفتوح فكان جملة عدد الهواء الطياب من قسمة الدائرة قنج[13] درجة والهواء المفسود من قسمة تلك الدائرة رز درجة [14] ثم قسمنا أحد هذا (!) الخطّين من طول محلّة البادهنج فكان الربع من محلّة البادهنج فاعلم أنّ محلّة هي طوله والموضع المفتوح هو عرضه من جهة المغرب والمسدود هو عرضه من جهة المشرق

وإن شئت من جهة الحساب فانسب عرضه من طوله وتأخذ جيب سعة أحد المنقلبين في ذلك العرض وهو كز مد في عرض ل حفطناه ثم زدنا سعة المشرق وهي كز ل دقيقة على ص فالجمع[15] قيز ل[16] دقيقة أسقطنا من ذلك ضعف سعة المشرق وهو نه الباقي سب ل دقيقة أخذنا جيبها فكان نج يج[17] دقيقة أضعفناها فكانت قو كو قسمنا عليها المحفوظ فحسل د يه لح ثانية وهو ربع الطول وربع قيراط الطول محبورًا (؟؟) فتقسم محلّة البادهنج بأربعة وعشرين قسمًا متساويًا[18] وتأخذ من تلك القسمة ستّ قراريط وربع قيراط فهو عرض

[8] أسمائه **MS** [9] فهو **MS** [10] The beginnings of a few lines of the **MS** are damaged. [11] مجهح **MS** [12] هيداب **MS** [13] قفجـ **MS** [14] درج **MS** [15] فاجمع **MS** [16] فيز ل **MS** [17] نجـ نجـ **MS** [18] متساوية **MS**

وإن كان الباقي أكثر من ص فاسقطه من قف وما بقي خذ ظلّه مبسوطًا[4] فهو ظلّ تلك الساعة فوق المركز

فإذا علمت أظلال الساعات لمداري[5] المنقلبين فخذ فتحة بالبركار وضعه في موضع الشخص ورجله الأخرى حيث وقعت على خطّ مدار ذلك البرج وينبغي أن تقسم دوره الأكبر والأصغر كلّ منهما يب قسمًا بقدر عدد البروج أو بستّة أقسام فإذا علّمت الساعات على جميع مدارات البروج فاجمع الساعات بعد أن تخطّ المدارات خطوطًا مستقيمة واكتب عليها عدد الساعات وأسماء البروج

وإن كان غليظه فوق وهو الذي يُعلَّق بخيط فاسقط ميله من تمام ارتفاع الساعة فما بقي خذ ظلّه مبسوطًا[6] فهو ظلّ تلك الساعة تحت المركز دائمًا وإن كان ميله أكثر من تمام ارتفاع الساعة فاعلم أنّ تلك الساعة لا يمكن وقوعها على ذلك المخروط

واعلم أنّ بعد المركز من الأفق بقدر ظلّ تمام ميله

وأمّا طول الشخص الذي تعمل في المخروط فهو أن تقسم المخروط وهو جنبه المائل بقدر أكثر أظلال الساعات وخذ من تلك القسمة يب فهو طوله في المخروط المعلّق وأمّا في المخروط القاعد فهو أن تقسم طوله بقدر مجموع ظلّ تمام ميله وأكثر أظلال الساعات وخذ من تلك يب فهو طوله

وكذلك إن أردت وضع ارتفاع على جنب المخروط فزد الارتفاع على ص واسقط من المجموع ميل المخروط إن كان غليظه أسفل واسقط ميله من تمام الارتفاع إن كان غليظه فوق فما بقي افعل كما ذكرناه أوّلًا فيخرج[7] المطلوب

<شكل> شكل المخروط المتعلّق الذي غليظه لفوق ورقّته أسفل لعرض لو

طول الشخص — (أسماء البروج) — بقية الساعات لا يمكن وقوعها على مدار السرطان

<شكل> شكل المخروط على بسيط الأرض ورقّته لفوق وغليظه أسفل

مركز الأفق — طول شخص المخروط القاعد — (أسماء البروج) — ساعاته لعرض لو

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[4] مبسوط MS [5] لمدار MS [6] مبسوط MS [7] فيخرج] تخرج MS

<شكل> شكل الحافر لعرض لو شمال

مركز — طول القامة — دائرة أوّل وقت العصر لسائر العروض التي عرضها لو — دائرة وقت الزوال لسائر العروض التي هي لو — (أسماء البروج)

D:51v البـــاب فط في معرفة وضع قوس العصر بحيث أن يكون دائرة كاملة

وهو أن تدير دائرة وتقسمها بأربعة أقسام كلّ ربع منها ص قسمًا ثم تضع المصطرة على مركزها وعلى سمت العصر من تلك القسمة ثم خذ فتحة بالبركار بقدر ظلّه المبسوط[1] وضع رجله في المركز والأخرى حيث وقعت على خطّ السمت فهو موضع علامة العصر فافعل ذلك كما تقدّم واجمع قوس العصر دائرة كاملة ثمّ اثبت تلك الدائرة من الدائرة الأولى وعلى هذا المقياس لأيّ عرض أردت وهذا لا يمكن إلّا في العروض الذي هي أكثر من الميل الأعظم والله أعلم

<شكل> دائرة قوس أوّل وقت العصر لعرض لو

المركز — طول الشخص — خطّ الزوال — خطّ المشرق — خطّ المغرب — دائرة أوّل وقت العصر لعرض لو

D:52r البـــاب ص في معرفة وضع المخروطات المتحرّكات (!) مثل المكاحل المخروطة والأشخاص المخروطة وغير ذلك

اعلم ميل ذلك المخروط ومعرفة ميله أن تأخذ فتحة بالبركار بقدر نصف قطر دائرة المخروط الكبرى وتسقط منها نصف قطر دائرة مخروطه[2] الصغرى فما بقي خذ بقدره فتحة بالبركار وادخل بها في عدد قسمة طول المخروط بحيث أن يكون طوله مقسومًا يب قسمًا متساويًا فما حصل من تلك الفتحة من تلك القسمة فهو ظلّ مبسوط خوذ ارتفاعه فهو تمام ميل ذلك المخروط فاحفظه

ثم افرض أن كان غليظه إلى أسفل فهو الذي يُفعَل على الأرض فزد على تمام ارتفاع تلك الساعة ص فما اجتمع اسقط منه تمام ميل المخروط فإن بقي أقلّ من ص فخذ ظلّه مبسوطًا[3] فهو ظلّ تلك الساعة تحت مركز شخص المخروط

[1] MS مبسوط [2] MS خرطه [3] MS مبسوط

منكوس وضع رجله على موضع تقاطع خطّ الغاية لخطّ الأفق واضرب برجله الأخرى على الغاية فهو موضع قوس العصر

وإن أردت خطّ الزوال فخذ فتحة بقدر ظلّ الزوال منكوس وضع رجله في موضع تقاطع <الأفق> لخطّ الغاية والأخرى حيث وقعت على خطّ الغاية فهو موضع خطّ الزوال < ... > فاجمعها[6] خطوطًا[7] فهي[8] مدارات < ... > قوس العصر وهذا الربع إن شئت أن يكون مخروقًا أو غير مخروق أعني أن يكون مصطحيًا[9] من نحاس أو خشب

<شكل>

المركز — طول الشخص — قوس أوّل وقت العسرِ آفاقي لسائر العروض

البـــاب فح في معرفة <وضع> الحافر الذي يكون فيه الظهر والعصر دوائر كاملة وهو متحرّك في البسيط وشخصه ثابت D:51r

وهو أن تدير دائرة وتقسمها بنصفين وتمدّ خطًّا يمرّ بالمركز وتقسم ذلك الخطّ بقدر مجموع ظلّ أوّل العصر لرأس المنقلبين وخذ من تلك القسمة يب فهو طول الشخص ثم تأخذ من تلك القسمة أيضًا بقدر ظلّ أوّل وقت العصر لرأس الجدي بفتحة بالبركار وتضع رجله موضع تقاطع الخطّ لدائرة ورجله الأخرى حيث وقعت عليه فهو موضع مركز الشخص ثم خذ بالبركار من تلك القسمة الأولى بقدر ظلّ العصر لكلّ برج وضع رجل البركار في المركز والأخرى حيث وقعت على الدائرة يمينًا ويسارًا فهي[10] علامات البروج فمدّها[11] خطوطًا إلى المركز واكتب بينها[12] أسماء البروج واكتب على الدائرة الأخرى قوس أوّل العصر ثم خذ فتحة بقدر طول الشخص وضعه في تقاطع خطّ البرج للدائرة ورجله الأخرى حيث وقعت على ذلك الخطّ فهي علامة الزوال فافعل ذلك لسائر البروج واجمعها[13] دائرة كاملة أو نقطًا[14]

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[6] MS فاجمعهما [7] MS خطوط [8] MS فهما [9] MS مصطحبا [10] MS فهم [11] MS فمدهم
[12] MS بينهما [13] MS واجمعهما [14] MS نقط

D:50r **البـــاب فو في معرفة وضع قوس العصر الآفاقي في البسيط ويسمّى الحافر**

وهو أن تدير دائرة وتقسمها ص قسمًا متساويًا ثم تفرض قامة لطيفة حتى تتحصّر ظلّ العصر داخل الدائرة من مبدأ الظلّ الذي تريد ثم تخذ خطوط الغاية إلى مركز الدائرة وتقسم تلك القامة يب وتجعل منها مصطرة وخذ من تلك القسمة بقدر طلّ العصر لأوّله وآخره إن اخترت وضع رجل البركار في المركز والأخرى حيث وقعت على خطّ الغاية الموافقة لظلّ العصر فإذا علّمت على خطوط الغاية علامات أوّل العصر وآخره فاجمعها[1] فهي[2] قسي العصر المطلوبة فاكتب على كلّ منها[3] اسمه فقد كُمِل الوضع وإن شئت أن تضع قوس الزوال فعلّم على كلّ غاية بقدر ظلّ الزوال واجمع تلك العلامات فهو المطلوب

واعلم أنّ السادسة وقوس أوّل العصر وآخره لا يمكن أن يُعلم غيرها[4] آفاقي إلّا أن يكون معه شيء آخر إمّا من خطوط الجيب أو من جهة الحساب أو يكون للعروض المسكونة خاصّة للشمس خاصّة تقريبًا جيّدًا

<شكل>

المركز — قوس الزوال لسائر العروض — قوس أوّل وقت العصر لسائر العروض — قوس أوّل العصر — قوس آخر وقت العصر لسائر العروض — قوس آخر العصر

D:50v **البـــاب فز في معرفة وضع قوس العصر الآفاقي المتحرّك في السطح القائم وشخصه ثابت[5]**

وقد وضعناه في لوح من خشب وقد يوضع في لوح من نحاس وذلك أن يكون طوله مثل عرضه حتى يُشكَّل فيه قوس العصر قريب من ربع دائرة ثم تقسمه بقدر الغايات من درجة إلى تسعين وتمدّ خطوط الغايات وتضع الأفق والوتد ثم تضع رجل البركار على موضع تقاطع الأفق لخطّ الغاية والرجل الأخرى حيث وقعت على خطّ الغاية التي تحت المركز وهو موضع رأس الشخص ثم اقسم تلك الفتحة يب قسمًا وخذ من تلك القسمة بقدر ظلّ العصر

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[1] MS فاجمعهما [2] MS فهما [3] MS منهما [4] MS غيرهما [5] MS ثابتًا

عدده وعلى البروج أسماءها[9] وأحسنها أن توضع فيها المدارات المرسومة في الساترة وهذه الرخامة ثابتة في الأرض وشخصها مجهول الطول وقد يعمل عليها ربع من نحاس مقوّر لأخذ الارتفاع وتكون قسي الدائر مركّبة على السمت فقد كُمِل الوضع إن شاء اللّه تعالى

<شكل> <الدائر المركّب على السمت>

(أسماء البروج) — هذه الرخامة وضعها الرئيس نور الدين السكندري في سطح الجامع العتيق بمصر وعليها ربع من نحاس مقوّر <كان> يأخذ به الارتفاع رحمة اللّه عليه

البـــاب فه في معرفة وضع الدائر المركّب على السمت لشكل آخر **D**:49v

أدر[10] دائرة وربّعها واقسم كلّ ربع منها ص قسمًا متساويًا[11] ثم خطّ خطًّا وهميًا من سعة مشرق المنقلبين إلى المركز ثم ضع مدارات البروج كما وضعتها[12] في الأصطرلاب وضع المصطرة على السمت الموافق لذلك الدائر[13] لرأس المنقلبين وعلى المركز وعلّم على <تقاطع> جنب المصطرة لمدارات السرطان ومدار الجدي ثم ضع رجل البركار على الخطّ المارّ بآخر الربع واجمع برجله الأخرى تلك العلامتين من المدار الأكبر إلى المدار الأصغر فهي[14] قسي الدائر واكتب عليه أعداده ثم اكتب على كلّ مدار اسم من جهة[15] اليمين واليسار فقد كُمِل الوضع

وهذه الدائرة أيضًا يُعلم منها الدائر إذا وُضِع في مركزها شخص مجهول الطول بحسب أن يكون على أرض مستوية تارّة يكون الشخص ثابتًا أو نقّالًا[16] أعني متحرّك لوقت الحاجة

<شكل> شكل الدائر المركّب على السمت لعرض لو

مشرق، مغرب — (أسماء البروج)

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[9] **MS** اسماهم [10] **MS** ادر corrected into ادير [11] **MS** متساوية [12] **MS** وضعتهم [13] لذلك الدائر **MS** om. [14] **MS** فهما [15] **MS** *bis* من جهة [16] **MS** نقال

D:48v البـــاب فج في معرفة وضع الدائرة الظلّية

وهو الذي يُعلَم منها الارتفاع والسمت في كلّ وقت إذا أردت وضعها أدر دائرة وتربّعها واقسم كلّ ربع منها ص قسمًا ثم مدّ خطوط السموت إلى مركز الدائرة ثم اقسم من المركز إلى الدائرة بقدر ظلّ أيّ ارتفاع أردت فاعمل من تلك القسمة مصطرة ثم خذ من تلك القسمة بقدر ظلّ كلّ ارتفاع وضع رجل البركار في المركز والأخرى أدر بها دائرة كاملة وإن شئت فقطعة من دائرة من سعة مشرق السرطان إلى سعة مغربه فهي المقنطرات ثم خذ من المصطرة بقدر يب قسمًا فهو طول الشخص وإن شئت فضع دوائر الأظلال فإنّها دوائر متساوية والمقنطرات غير متساوية وقد وضعنا هذه الأشكال كلّها في رخامة واحدة واكتب عليها جميع ما يُعلَم منها وسوف نذكرها في موضع الحاجة ونشكّلها إن شاء الله تعالى

<**شكل**> <شكل الدائرة الظلّية>

طول الشخص — سعة مشرق الجدي — سعة مغرب الجدي — يوضع على أرض مستوية في سائر العروض — وإنّما سعة مشرق الجدي ومغربه بزيادة خطوط السمت

D:49r البـــاب فد في معرفة وضع الدائر المركّب على السمت

أدر دائرة وربّعها واقسم كلّ ربع منها ص ثم مدّ خطًّا وهميًا من[4] سعة مشرق رأس كلّ برج إلى المركز واقسم نصف القطر بسبعة أقسام إن شئت متساوية أو غير متساوية وضع المصطرة على السمت الموافق لذلك الدائر وعلّم على مدار تلك الدرجة فإذا كملت العلامات فاجمعها[5] قسيًا[6] واكتب عدد الدائر وعدد الساعات المستوية والزمانية إن كان الوضع بأجزاء الساعات الزمانية

والأصحّ أن تعلّم على موضع الدائر الموافق لذلك السمت لرأس كلّ برج واجمع العلامات قسيًا[7] أو نقطًا[8] وتضع رجل البركار في المركز وعلى علامة كلّ برج وأدر برجله قوسًا من سعة مشرقه إلى سعة مغربه واكتب على الدائر

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[4] من *bis* **MS** [5] فاجمعهما **MS** [6] قسي **MS** [7] قسي **MS** [8] نقط **MS**

البـــاب فا في معرفة وضع بسيطة فضل الدائر D:48r

وهو أن تدير دائرة وهمية وتربّعها وتقسم كلّ ربع ص قسمًا متساويًا ثم ضع المصطرة على سمت فضل الدائر وعلى المركز ثم خذ فتحة بقدر ظلّ الارتفاع وضع رجل البركار في المركز والأخرى حيث وقعت بجنب المصطرة فعلّم علامة ولا تزال تفعل كذلك حتى تكمل علامات فضل الدائر لرأس الجدي ثم افعل كذلك لرأس السرطان فإذا كملت علامات السرطان والجدي فاجمعهما خطوطًا مستقيمة فهي خطوط <فضل> الدائر فاكتب عليه أعدادها فإذا اتهى <علامات> مدار الجدي فاجمع علامات الاعتدال فإذا اتهى علامات[1] الاعتدال فاجمع علامات الثور فإذا كُمِلت فاجمع علامات الجوزاء فقد كُمِل الوضع

<شكل> بسيطة فضل الدائر لعرض لو

المركز — طول الشخص

البــاب فب في معرفة وضع بسيطة الساعات المستوية D:48r

وهو كما فعلت في الزمانية وإنّما تارّة تجمع الساعات مبتدئاً من أوّل النهار وتارّة تجمعها[2] من نصف النهار واجمعهما[3] من مدار الجدي إلى مدار السرطان فإذا كُمِل مدار الجدي اجمعهما على مدار الحمل فإذا كُمِل فاجمعهما على مدار الجوزاء فقد كُمِلت الساعات فاكتب أعدادها

<شكل> بسيطة الساعات المستوية لعرض لو

طول المري — مشرق، مغرب — سرطان (مرّتان)، حمل *setminus* ميزان، جدي (مرّتان)

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[1] علامة MS [2] تجمع MS [3] وجمعهما MS

D:47v

جدول ارتفاع الساعات وارتفاع العصر وسعة المشرق
لرأس * البروج لعرض لو

	سرطان		جوزاء أسد		ثور سنبلة		حمل ميزان		حوت عقرب		دلو قوس		جدي	
	دائر	ارتفاع	دائر	ارتفاع	دائر	ارتفاع	دائر	ارتفاع	دائر	ارتفاع	دائر	ارتفاع	دائر	ارتفاع
ا	يح جـ	يجـ يو	يز لو	يجـ ح	يو كد	يجـ ب	يه	يب د	يجـ لو	ي يو	يب كد	ح كجـ	يا يز	ح و
ب	لو ز	كز كد	له يب	كز يد	لب مز	كو ذ	ل	كجـ نا	كز يجـ	ك يا	كد مح	يو ط	كجـ يجـ	يه يو
جـ	ند ي	ما نه	نب مح	ما مجـ	مط يا	لح له	مه	لد ند	م مط	كح ند	لز يب	كجـ ند	له ن	كا ل
د	عب يد	نو ل	ع كد	نه يا [a]	سه لد	ن ل	س	مد كح	ند كو	لو و	مط لو	كح مح	مز مو	كه نح [c]
ه	ص يز	ع يا	فح ذ	سز ح	فا نح	س لا	عه	نا كد	سح ب	م كز	سب ذ	لب يجـ	نط مجـ [d]	كط و
و	قح كا	عز له	قه لز	عد يو	صح كا	سه لب	ص	ند ذ	فا لط	مب كح	عد كجـ	لجـ مد	عا لط	ل كه
أوّل العصر	نا نه	لط كا	مز كد	لز نجـ	مب ند	لد ل	لح يو	ل د	لد نو	كه لب	لجـ مز	كا مط	لب نا	ك يو
آخر العصر	لب يا	كد يز	ل يد	كجـ ما	كز لح	كب ي	كه ط	ك ز	كد ك	يز نه	كجـ لا [b]	يه نز	كجـ لز	يه ز
	سعة مشرقه كطلح		سعة مشرقه كه كا		سعة مشرقه يد يح		سعة مشرقه ذ ذ		سعة مشرقه يد يح		سعة مشرقه كه كا		سعة مشرقه كطلح	

* MS رؤس   [a] MS يه يا   [b] MS كجـ نا   [c] MS كه يح   [d] MS نط مح

D:47r

جدول لظلال الساعات مبسوطًا ومنكوسًا وظلّ أوّل العصر وآخره وسمته لرأس * البروج

	سرطان		جوزاء / أسد		ثور / سنبلة		حمل / ميزان		حوت / عقرب		دلو / قوس		جدي	
	ظل مبسوط	ظل منكوس	ظل مبسوط	ظل منكوس	ظل مبسوط	ظل منكوس	ظل مبسوط	ظل منكوس	ظل مبسوط	ظل منكوس	ظل مبسوط	ظل منكوس	ظل مبسوط	ظل منكوس
ا	ن نه	ب ن	نا كز	ب مح	نا نا	ب مو	نو ح	ب لد	سو يو	ب كد !	فالح	ا مد	فد يح	ا ما [l]
ب	كجي	و يج	كجك	و يا	كد لد	ه نا [d]	كزط	ه يط	لبلح	د كز	ما كد	جكح	مجنط [m]	ج يو
ج	يجكب [a]	ي مح	يجكح	ي مج	يه ا	ط لد [e]	يز ي	ح كب	كا مج	ولز	كز ه	ه ك	ل كح	د مه
د	زلط ! [b]	يح ح	ح كا	يز يد	ط يج	ي لد	يب يد	يا مز [f]	يو كه	ح مه	كا مط	و لو	كزمب	ه مط
ه	د يط	لجيه	كز يد !!	كح كه	و مز	كا يج	ط له [g]	يه ا	يد ه	ي يج	يط يه [k]	ز ل	كا يط [n]	و مد
و	بلح	ند لب	جكب	مب له [c]	ه كح	كو كج	ح مج	يو لا [h]	يجز	ي نح [i]	يز نح	ح ا	ك كه	ز ج
أوّل العصر	يدلح	ط ن	يه كب	ط كب	يزكح	ح يه	ك مج	و نز	كه ز	ه مد	كط نح	د مط	لب كه	د كو
آخر العصر	كولح	ه كه	كزكب	ه يو	كطكح	د لط !	لب مج	دكج	لز ز	ج نج [j]	ما نح	ج كه	مد كه	ج يد
	سمت عصره ذ ب						سمت عصره مدكد						سمت عصره مونب	

* MS رؤس   [a] MS يجك   [b] MS ن لط   [c] MS كب له   [d] MS كا نا   [e] MS ط كد   [f] MS ا مز   [g] MS ط كه   [h] MS نز لا
[i] MS يلح or ي نح   [j] MS ج نج   [k] MS لط كه   [l] MS ا يا   [m] MS مج لط   [n] MS كا نط

الباب ف

تمام جدول البسيطة لعرض لو للساعات المستوية والزمانية وارتفاعها[9] وظلّها[10] وسمتها[11] لرأس الجدي

دائر	ارتفاع	ظل مبسوط	ظل منكوس	سمت
جـ	ب ب	شلح ل [a]	ۮ كه	لا لط
و	د د	قسح ن	ۮ ن	لجكد
ط	و و	قيب كب	ا يز	لهلح
يب	ح ح	فجنح	ا ما	لز ط
يه	ي ب	سز مط	ب ز	لط ا
يح	يا نب	نز ح	ب لا	ما ۮ
كا	يجلح [b]	مط كز [c]	ب نه	مجو
كد	يه ك	مجمز	جـ يز	مه يه
كز	يز ۮ	لط يد	جـ م	مز ل
ل	يح م	لهلج	د جـ	مطلج
لج	ك يه	لبكح	د كه	نبلح
لو	كا لو	ل يز	د مو	ند مج
لط	كب ن	كح كز	ه د	نزك
مب	كجنو	كز ب	ه ك	سط و
مه	كه ۮ	كه مد	ه لو	سبمح
مح	كوۮ	كد له	ه نا	سه ما
نا	كو نو	كجلح	و و	سح ما
ند	كزمح	كب مو	و ك	عا م
نز	كحلح	كا نط	ولج	عد مد
س	كط كو	كا يه	و مو	عزمو
سج	كط نو	ك مط	و نه	ف مح
سو	ل يه	ك لب [d]	ز ا	فجنب
سط	ل كا	ككح	ز ب	فو نو
عا لط	ل كه	ك كه	ز جـ	ص ۮ

[a] رلح ا **MS** [b] يجلج **MS** [c] مه كز **MS**
[d] ك ل **MS**

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[9] وارتفاعهما **MS** [10] وظلهما **MS** [11] وسمتهما **MS**

دائر	ارتفاع	ظل مبسوط	ظل منكوس	سمت	جهة
نز	مد يجـ[a]	يب ك[b]	يا ما	ذ مو	جنوب
س	مو لط	يا يط	يب مب	ب كط	جنوب
سجـ	مط و	ي كجـ	يجـ نب	دلح	جنوب
سو	نالجـ	ط لب[c]	يه ه	و ند[d]	جنوب
سط	نجـ نط[e]	ح مجـ	يو ل	ط يز	جنوب
عب	نو كد	ز نط	يح جـ	يا مو	جنوب
عه	نح مد	ز يح	يط مد	يد يح	جنوب
عح	سا ذ	و لط	كا لط	يز يح	جنوب
فا	سجـ يه	و جـ	كجـ مط	ك لد	جنوب
فد	سه ل	ه كط	كو كا	كد ه	جنوب
فز	سز مه	د نه	كط يح	كح يو	جنوب
ص	ع ذ	د كب	لب نح	لب يح	جنوب
صجـ	عب ذ	جـ ند	لو نو	لو كا	جنوب
صو	عجـ م	جـ لا	م نه	م كه	جنوب
صط	عه ذ	جـ يجـ	مد مز	مه له	جنوب
قب	عو يه	ب نز	مح نط	نح ذ	جنوب
قه	عز يا	ب مجـ	نب مجـ	عجـ ذ	جنوب
قح كا	عز له	ب لح	ند لب	ص ذ	جنوب

[a] **MS** مد يح　[b] **MS** يز ك　[c] **MS** ط ل　[d] **MS** و ند
[e] **MS** نجـ مط

D:95v **جدول البسيطة لعرض لو للساعات الزمانية والمستوية وارتفاعها[7] وسمتها[8] وأظلال مبسوطًا لرأس السرطان خاصّة وللارتفاع والظلّ والسمت إذا كان الدائر ثلاث درج ثلاث درج**

دائر	ارتفاع	ظل مبسوط	ظل منكوس	سمت	جهة
ج	ب يب	شيب كج	ۮ كز	كح ۮ	شمال
و	د كد	قنه مط	ۮ ند	كو كد	شمال
ط	و لو	قجمه	ا كج	كد مط	شمال
يب	ح مح	عز له	ا نا	كج يد	شمال
يه	يا ا	سالح	ب كا	كا لط	شمال
يح	يج يج	نا ز	ب مط	ك د	شمال
كا	يه لد	مجه	جك	يح كط	شمال
كد	يز نه	لز ز	ج نج	يز ند	شمال
كز	ك يو	لب كو	د كو	يه ك	شمال
ل	كب لز	كح مج	ه ۮ	يج م	شمال
لج	كد نح	كه مز	ه لو	يب ۮ	شمال
لو	كز ك	كج يد	و يو	ي كب	شمال
لط	كط مو	ك نز	و نب	ح مو	شمال
مب	لب يا	يط ب	ز لج	و ب	شمال
مه	لد لو	يز كب	ح يز	ه م	شمال
مح	لز ۮ	يه نه	ط ج	د و	شمال
نا	لط كد	يد لز	ط نا	ب لا	شمال
ند	ما مح	يج كو	ي مه	ۮ ند	شمال

/...

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[7] MS وارتفاعهما [8] MS وسمتهما

D:47r and 47v

البـــاب عط في معرفة وضع البسيطة ومدارات البروج[1]

وهو أن تربّع الرخامة وتمدّ خطًّا في وسطها فهو خطّ الزوال ثم أدر دائرة يكون مركزها <على> خطّ الزوال ومدّ خطًّا يمرّ بالمركز <و> يقاطع خطّ الزوال فهو خطّ المشرق والمغرب ثم خذ <على الدائرة> من موضع تقاطع خطّ المشرق للدائرة[2] بقدر سمت كلّ ساعة إلى جهة سمتها وعلّم علامة وضع المصطرة على تلك العلامة و <على> المركز وخذ فتحة بالبركار بقدر ظلّ الساعة مبسوطًا وضع رجله في المركز والأخرى حيث وقعت على جنب المصطرة فهو موضع الساعة فافعل ذلك للمنقلبين ثم صل الساعات للمدارين وأمّا مدار الحمل فمدّه خطًّا مستقيمًا على ظلّ الزوال وسائر البروج بظلّ الساعات المبسوط[3] فافهم تصب

<شكل> <شكل البسيطة المركّب عليها الـ> ساعات <الـ> زمانية لعرض لو

شمال، جنب، مشرق، مغرب — أولة، ثانية ... حادية عشر — (أسماء البروج)

D:47v

البـــاب ف في معرفة وضع البسيطة التي مركّب عليها المقنطرات والساعات الزمانية

أمّا الساعات فهي[4] كما بيّناها[5] أوّلًا وأمّا المقنطرات فخذ ظلّ ارتفاع تلك المقنطرة التي[6] تريد من أجزاء طول الشخص بفتحة بالبركار وضع رجله في مركز البسيطة والرجل الأخرى على مدار الجدي وأدر قوسًا إلى حيث يصل فإذا انتهى المدارين فأدرهما قوسًا من مدار السرطان من جهة المشرق والمغرب فقد كملت المقنطرات فاكتب عليها أعدادها وأعداد الساعات

<شكل> بسيطة لعرض لو

شمال، جنب، مشرق، مغرب

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[1] See the note in the translation. [2] لخطّ الزوال MS [3] المبسوطة MS [4] فهما MS [5] بيناهم MS [6] الذي MS

D:95r

البـــاب عح في معرفة <وضع> الأصطرلاب الخطّي

وهو أن تتّخذ مصطرة مصطحية[6] أو عكّازًا يكون مثمّن الأضلاع أو مسدّسًا أو مربّعًا أو مثلّثًا وكذلك إذا كان مصطحيًا واكتب عليه جداول العمل واقسمه من موضع المقبض إلى موضع المسك ص قسمًا غير متساوية[7] وذلك على قسمة الجيب كما قسمت أحد الضلعين[8] لذات الشعبتين[9] ولذلك ما ذكرنا وضع هذا الأصطرلاب مع جملة الأصطرلابات فإنّه ليس هو من أشكالهم ولا جنسهم بل هو شكل المساطر أو شكل ذات الشعبتين فذكرناه في موضع يُناسب ذكره

فإذا أردت وضعه فاثقب خرمين في طرفيه أحدهما موضع المسك والآخر في أسكفّة (؟؟) موضع المقبض على قدر ما يريد الواضع واقسم ما بين الخرمين ص قسمًا <غير> متساوية[10] على قسمة الجيب من القوس وذلك أن تقسم طول العكّاز في موضع آخر س قسمًا متساويًا وتعلم جيب قوس خمسة خمسة أو غير ذلك وخذ من تلك القسمة بقدر < ... > فانحص (؟؟) القوس من الجيب وانقل البركار بفتحته إلى أحد ضلعي[11] العكّاز من المسك إلى مقبض واكتب عليها عدد الارتفاع ثم خذ خيطًا[12] طوله قدر ما بين المقبض والمسك مرّتين وربع وسدس تقريب وأمّا التحرير فتقسم ما بين المقبض والمسك س قسمًا[13] متساويًا وخذ من تلك القسمة قمد ن دقيقة فهو طول الخيط من غير عقدتين الخيط

وأمّا الجداول المكتوبة عليه ولا يحتاج أن نذكرها فإنّها من الجداول المتقدّمة ولا يمكن تصويره في الورق غير هذا الشكل ولم يكن فيه أحسن من أخذ الارتفاع فلذلك مثلناه

<شكل> شكل الأصطرلاب الخطّي وهو آلة قد عُدِمت في هذا الزمان

بقية الخيط من جهة وجه الأصطرلاب — وجه الخطّي — قسمة المقنطرات لأخذ الارتفاع — خيط الشاقول إذا كان الارتفاع نط — بقية الخيط من جهة ظهر الأصطرلاب — عقدة الشاقول — الشاقول — المقبض

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[6] مصطحبة MS [7] متساويا MS [8] الطلعين MS [9] Cf. Chapter 105. [10] متساويا MS [11] طلعي MS [12] خطا MS [13] قسمًا om. MS

والثاني هو الذي يعملوه خطًّا مستقيمًا[2] وهو سقيم والصحيح أن يكون نقطًا معوجّة وهو مركّب على الجيب **بيانه** أن تضع المصطرة على الغاية والمركز وتدخل بارتفاع العصر في الجيب المبسوط إلى جنب المصطرة وعلّم علامة ولا تزال تفعل ذلك إلى أن تُنهي الغايات وتنقّطها[3] نقطًا معوجّة

والثالث : تضع رجل البركار في المركز والأخرى على خطّ نصف النهار على جيب ارتفاع العصر وتنقل رجله التي على جيب ارتفاع العصر حتى تضعها على الخطّ الشعاعي للغاية وتعلّم في الربع علامة فإذا انتهت علامات العصر فاجمعها قوسًا

والرابع: تضع رجله في المركز والأخرى على جيب الغاية وتنقل رجله التي على جيب الغاية[4] حتى تضعها على الخطّ الشعاعي الموافق لارتفاع العصر <وعلّم علامة حتى تكمّلت علامات العصر> فنقّطها[5] نقطًا وهذا < ... >

<والخامس: تضع رجله في المركز والأخرى على جيب الغاية وتنقل رجله التي على جيب الغاية حتى تضعها على خطّ جيب ارتفاع العصر وتعلّم علامة ولا تزال تفعل ذلك إلى أن تكمّلت العلامات وتنقّطها نقطًا معوجّة ... >

< ... > والذي قبله صفة الجوكان

واعلم أنّ الربع المجيّب لا يحتاج إلى قوس من هذه الخمسة وإنّما أردنا أن نعرف من يريد الوضع لهذه الأقواس

<شكل> شكل خطوط العصر آفاقية في الربع المجيّب

[2] خط مستقيم MS [3] وتنقطهم MS [4] Here the words على خطّ نصف النهار جيب الغاية وانقل رجله التي على جيب الغاية are crossed out in **MS**
[5] ونقطعها **MS**

<table>
<tr><td colspan="8">هذا الجدول يُعمل في سائر العروض المسكونة تقريبًا من بلد لا عرض له إلى عرض مح</td></tr>
<tr><td colspan="8">جدول ارتفاع الساعات للشمس خاصّة
وللكواكب الذي بعدها أقلّ <من> الميل الأعظم</td></tr>
<tr><td>غاية</td><td>أولى [*]</td><td>ثانية</td><td>ثالثة</td><td>رابعة</td><td>خامسة</td><td>أول
وقت العصر</td><td>آخر
وقت العصر</td></tr>
<tr><td>ي</td><td>ب لا</td><td>ه ذ</td><td>ز ذ</td><td>ح لط</td><td>ط م</td><td>ح لا</td><td>ز كو</td></tr>
<tr><td>ك</td><td>د نج [a]</td><td>ط مط</td><td>يج مط</td><td>يز يب</td><td>يط يد</td><td>يد نو</td><td>يا ند</td></tr>
<tr><td>ل</td><td>ز يا</td><td>يد ل</td><td>ك ل</td><td>كه ما</td><td>كح ند</td><td>ك و</td><td>يه ذ</td></tr>
<tr><td>م</td><td>ط يه</td><td>يز مه</td><td>كز مه</td><td>لج نب [d]</td><td>لح كه</td><td>كد لب</td><td>يز كد</td></tr>
<tr><td>ن</td><td>يا ب</td><td>كب لب [c]</td><td>لب كه</td><td>مب نه</td><td>مز مح</td><td>كح لج</td><td>يط كه</td></tr>
<tr><td>س</td><td>يب "ل" [b]</td><td>كه م</td><td>لز ك</td><td>مح لط</td><td>نو نا [e]</td><td>لج يز</td><td>كا يا</td></tr>
<tr><td>ع</td><td>يج له</td><td>كح ب</td><td>ما ح</td><td>ند لب</td><td>سه يز</td><td>لو يج</td><td>كب نه</td></tr>
<tr><td>ف</td><td>يج مه</td><td>كح كط</td><td>مج لد</td><td>نح لو</td><td>عب ي</td><td>م مط</td><td>كد نب</td></tr>
<tr><td>ص</td><td>يد ل</td><td>ل ذ</td><td>مه ذ</td><td>س ذ</td><td>عه ذ</td><td>مه ذ</td><td>كو لد</td></tr>
</table>

[*] اولة **P**,**D**   [a] د يحـ **D**   [b] يب ب **P**,**D**   [c] ي ل **D** (but note that in **P** كب looks like a ى , and that لب resembles a ل !)   [d] لحـ سب **D**   [e] Part of the ink of نو is erased in **P** so that it looks like نر , yet the traces of the original و can still be recognised on the photocopy.

<**ملاحظة**>   وأمّا ارتفاع أوّل العصر وآخره محرّرًا (!) ليس تقريبًا[20]   End of **P**

البـــاب عز في معرفة وضع أقواس العصر في الأرباع المجيّبة   **D**:94v

فإنّ قوس العصر لكلّ منها آفاقي وأكثر اختلاف أشكاله في أرباع الجيوب فلذلك اخترنا وضعها وبيان كلّ قوس منها[1] مخالفًا للآخر وقد تكون أكثر من خمسة أقواس وإنّما الاختصار بلغه

فإذا أردت وضع القوس الأوّل وهو مشهور ويسمّى مساطر الظلّ الاثنا عشري <فعلّم على القسم الثاني عشر من خطّ آخر الربع الستّيني مبتدئاً من المركز ومدّ خطّا مستقيما من هذه العلامة إلى قوس الربع موازيا لخطّ أوّل الربع>

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[20] تقريب **P**,**D**. In the lower margin of **P** is a colophon in a later hand: وليكن هذا آخر الغرض فمن وجد خللًا فليصلحه تمّ المجلّد والحمد لله وحده وهو ولي التوفيق وحسبي الله ونعم الوكيل

[1] منهما **MS**

D:94r
P:38v

معرفة استخراج هذا الجدول وهو أن تأخذ جيب الغاية من الجداول المحلولة دقيقة دقيقة ثم خذ ربع جيب الغاية وقوّسه فهو ارتفاع الأولى[16] ثم خذ نصف جيب الغاية وقوّسه فهو ارتفاع الثانية ثم خذ نصف وخمس جيب الغاية وقوّسه فهو ارتفاع الثالثة ثم خذ ثلثي جيب الغاية وخمسها وقوّسه فهو ارتفاع الرابعة ثم خذ ثلثي جيب الغاية وخمسها وعشرها وقوّسه فهو ارتفاع الخامسة وهذا العمل تقريبًا للشمس خاصّة في العروض المسكونة

فإنّي باشرتها بعمل السهم والجيب فوجدت فيها تقريبًا يسيرًا فاخترت أن أضع لها جدولًا لكثرة صعوبة ارتفاع الساعات الآفاقية من جهة الحساب لأن يُلزِم من ذلك أن تغيّر كلّ عرض وتكتب له جدولًا وكان يطول الشرح في ذلك وكانت مخصوصة للعرض الذي حسبتَ له ولا يمكن أن يُكتَب عليها آفاقية فلمّا نظرت أن في هذا الجدول تقريبًا يسيرًا ومنفعته عامّة كبيرة[17] فاثبته في كتابي هذا[18] لينتفع به ويسهّل على من يريد أن يضع المكاحل وساق الجرادات[19] وغيرها من الساعات المخصوصة للشمس خاصّة لسائر العروض المسكونة وإن كُتِب عليه آفاقي وعُنِي به أنّه لسائر الآفاق المسكونة تقريبًا كان جيّدًا فإن عُنِي به أنّه آفاقي للشمس والكواكب لسائر العروض المسكونة والخراب كان خطأً كبيرًا

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16 الأولة **P,D** 17 عاما كبيرا **P,D** 18 هذا om. **D** 19 الساق جرادات **P**; الساق جراوات **D**

يؤخذ بها الارتفاع إذا وُضِع على هذه الصورة

ثم اقسم نصف القطر وهو ضلع[13] الزاوية المتساوي للآخر بثلاث أقسام من كلّ ناحية ومدّه خطًّا مستقيمًا وهو مدار الجدي ثم اقسم ما بين مدار الجدي والقطر الذي هو مدار السرطان بستّة أقسام من الناحيتين ومدّها[14] خطوطًا مستقيمة فهي[15] خطوط المدارات ثم ضع المصطرة على المركز ومدّ ارتفاع كلّ ساعة وعلّم على تقاطع جنب المصطرة لذلك المدار إلى أن تكمل الساعات فاجمعها

<شكل> شكل ساعات الزاوية لعرض لو

بخيط واحد في المركز

الباب عو في معرفة وضع ساق الجرادة[1] المصطحية[2] والمكحل المستدير[3] وشخصها ثابت[4] D:93v P:38r

وذلك أن تتّخذ لوحًا[5] من خشب أو غيره مصطحي[6] أو مكحل مدوّر < ... > واقسم كلّ منهما ص قسمًا واكتب على كلّ مدار غايته ومدّها[7] خطوطًا[8] معوجّة مجموعة على نقطة واحدة ثم أدر ربع[9] دائرة واقسمها ص قسمًا ثم ضع المصطرة على المركز وعلى ارتفاع تلك الساعة وعلّم على تقاطع جنب المصطرة لذلك[10] المدار إلى أن[11] تُكمل جميع الساعات على سائر المدارات وكذلك قوس العصر[12] فاجمعها واكتب عليها أعدادها واعلم أنّ طول الشخص هو مقدار ما بين السادسة وخطّ ص على زوايا قائمة[13] واعلم أنّ خطّ ص هو مسقط حجر الشخص

<شكل> هذا الربع يعلم به ارتفاع الشمس

قوس أوّل وقت العصر — قوس الزوال — مركز[14] الشخص الثابت — طول الشخص الثابت[15]

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13 طلع P,D 14 ومدهما P,D 15 فهما P,D 1 الساق جرادة P,D 2 المصطحبة P 3 المستدير] المسيد بعرف D 4 ثابتًا P,D 5 لوح P,D 6 مصطحب P,D 7 ومدهما P,D 8 خطوطًا om. D 9 أدر ربع] ادربع P 10 لذالك P 11 الا ان P 12 وكذلك قوس العصر marg. P 13 على زوايا قائمة] على قامة D; على زاوايا قامة P 14 مر مركز P,D 15 طول الشخص الثابت om. D

D:92v
P:37r

البـــاب عد في معرفة وضع الساعات الآفاقية تقريبًا لسائر العروض المسكونة

وهو من عرض ى ى إلى عرض مح وهو أحسن الساعات وأشرفها ولذلك ختمنا به عشرة أرباع وهذه الأرباع المخصوصة لكلّ عرض أشكالها لا يتناهى وشرحها يطول والاختصار بلغه

إذا أردت وضعه فأدر <ربع> دائرة واقسمه[1] ص بعدّ التربيع ثم ضع المصطرة على كلّ يه درجة من تلك القسمة وعلى المركز ومدّه خطًّا مستقيمًا فهي[2] خطوط الساعات ثم اقسم نصف القطر بنصفين واثبت[3] رجل البركار وأدر برجله الأخرى نصف دائرة فهي قوس الغاية ثم اقسم خطّ آخر الربع س[4] وخذ من تلك القسمة بقدر جيب خمسة أو غير ذلك ومدّها[5] خطوطًا موازية لخطّ أوّل الربع فهي[6] خطوط الجيوب المبسوطة واكتب على الساعات أعدادها وعلى القوس قوس الغايات وهذا الربع يُعلم منه الدائر لكلّ ارتفاع أحسن من ربع الساعات الآفاقية[7] فإنّه أوسع من ساعاته

وقد تعمل فيه خطّ مستقيم من أوّل الربع إلى آخره وتكتب عليه عصر وذلك مستقيم وإنّما يكون نقطًا بمعوجّة فتركناه لأنّه مشهور وهذا غريب

<**شكل**> شكل الساعات لسائر العروض المسكونة للشمس خاصّة ولكلّ كوكب بعده أقلّ من الميل الأعظم تقريبًا جيّدًا
وهذا الربع بخيطٍ واحدٍ

D:93r
P:37v

البـــاب عه في معرفة وضع ساعات الزاوية

وهو أن تدير[8] ربع دائرة وهمية فتربّعها[9] بخطّين وتقسم[10] ذلك الربع ص قسمًا متساويًا قسمةٍ وهميةٍ أيضًا ثم مدّ خطّ وتر الربع وهو ضلع[11] الزاوية الأطول ثم ضع المصطرة على المركز وعلى كلّ قسم من الأقسام الوهمية وعلّم على تقاطع جنب[12] المصطرة لخطّ الوتر فإذا كُمِلت معك علامات الوتر وهو الذي

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[1] واقسمها **P,D** [2] فهما **P,D** [3] ثبت **P,D** [4] ص **P,D** [5] ومدهما **P,D** [6] فهما **P,D** [7] ربع ساعات الآفاقية crossed out **D** [8] ندير **P** [9] فنربعها **P** [10] ونقسم **P** [11] طلع **P,D** [12] الزاوية **P,D**

<شكل> شكل الساعات لعرض لو

وهذا الربع بخيطٍ واحدٍ

البـــاب عج في معرفة وضع ساعات دوائر التعديل

D:92r
P:13v

وهو أن تدير ربع دائرة وتربّعها وتقسم قوس الربع ص قسمًا متساويًا ثم تضع رجل البركار في أوّل قوس الربع والأخرى على مه درجة من القوس وانقلها إلى خطّ أوّل الربع وعلّم علامة ثم انقل البركار حتى تضعه في المركز وعلى[1] تلك العلامة وأدر ربع دائرة صغيرة فهو مدار رأس الجدي ثم اقسم ما بين مدار الجدي وقوس الربع بنصفين على ذلك الخطّ <وعلّم فضع رجل البركار على هذه العلامة وأدر ربع دائرة وسيطة> فهو مدار الحمل ثم ضع[2] المصطرة على المركز وعلى ارتفاع سادسة الحمل والجدي والسرطان وعلّم على تقاطع المصطرة لمداراتها[3] واعلم أن مدار السرطان قوس الربع فاجمع تلك العلامات الثلاثة فهو قوس الزوال[4] ثم ضع[5] المصطرة على المركز وعلى غاية ارتفاع رأس الثور والجوزاء والعقرب والقوس وعلّم على تقاطع[6] المصطرة لقوس السادسة ثم ضع[7] رجله في المركز والأخرى على كلّ علامة وأدر قوسًا فهي[8] المدارات المطلوبة فاكتب على كلّ منها اسم برجيه ثم ضع المصطرة على ارتفاع كلّ ساعة وعلى المركز وعلّم موضع تقاطعها[9] لمدار البرج فإذا كُمِلت علامات الساعات فاجمعها[10] بالبركار قسيًا[11] فهي[12] الساعات الزمانية فاكتب عددها

<شكل> شكل الساعات لعرض لو

وهذا الربع بخيطٍ واحدٍ

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[1] وعلى] وكلّ D [2] اضع P [3] لمداراتهما P,D [4] الزاوال P [5] اضع P [6] تقاطعه P,D [7] اضع P [8] فهما P,D [9] تقاطعهما P,D [10] فاجمعهما P,D [11] قسي P,D [12] فهما P,D

D:91r
P:12v

البـــاب عا في معرفة وضع هذه الساعات وتسمّى ساعات التسعيني

وهو أن تدير ربع دائرة وتربّعها وتقسمها ص قسمًا متساويًا ثم تقسم خطًّا أوّل الربع كذلك ثم تضع رجل البركار في مركز الربع وعلى تمام غاية ذلك البرج وتنقلها إلى خطّ آخر الربع إلى أن تكمل[1] سائر البروج ثم انقل البركار حتى تضعه في نقطة آخر الربع ورجله الأخرى على كلّ علامة من البروج وأدره قوسًا فهو مدار ذلك البرج ثم ضع[2] رجل البركار في المركز أيضًا ورجله الأخرى على تمام ارتفاع الساعة من قسمة خطّ التربيع واضرب برجله الأخرى على مدار ذلك البرج الذي أردت وعلّم على كلّ مدار بقدر ارتفاع كلّ ساعة تفعل ذلك إلى الخامسة فإذا علّمت سائر علامات البروج فاجمعها قسيًا[3] بالتقارب والتباعد واكتب على كلّ مدار برجيه وعدد الساعات

<شكل> شكل الساعات لعرض لو[4]

وهذا الربع بخيطٍ واحدٍ[5]

D:91v
P:13r

البـــاب عب في معرفة ⌈ وضع هذه الساعات وتسمّى ساعات الشظيّة ⌉[6]

وهو أن تدير <ربع> دائرة وتربّعها بخطّين وتقسم قوس الربع ص قسمًا متساويًا ثم تقسم خطّ التربيع ص قسمًا متساويًا ثم تضع المصطرة على المركز وعلى خمسة عشر من قوس الربع ومدّها[7] خطوطًا فهي[8] المدارات فاكتب عليها[9] أسماء البروج كلّ في مداره ثم ضع[10] رجل البركار في المركز ورجله الأخرى على ارتفاع الساعة الأولى[11] وانقلها بتلك الفتحة إلى مدار ذلك البرج وعلّم علامة ثم ضع رجله على ارتفاع الثانية وانقلها إلى مدار ذلك البرج وعلّم علامة ثانية ثم افعل ذلك لسائر الساعات فإذا كملت علامات الساعات فاجمعها بالبركار إن أمكن وإلّا نقّطهم نقطًا فهي[12] قسي الساعات الزمانية فاكتب عليها أعدادها وعرض البلد

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[1] تّكمل **P,D** [2] اضع **P** [3] قسي **P,D** [4] Caption om. **D** [5] Text om. **D** [6] ⌈…⌉ : وضع هذه الشظية **D**; وضع هذه وتسمّى الشظية **P**. On the reading شظية see the remarks in the translation. [7] ومدهما **P,D** [8] فهما **P,D** [9] عليهم **P,D** [10] اضع **P** [11] الاوله **P,D** [12] فهما **P,D**

مدار كلّ منها[4] واجمع هذه[5] العلامات الثلاث فهي قوس السادسة ثم ضع[6] المصطرة على ارتفاع أوّله وعلى المركز وعلّم على كلّ من المدارات الثلاث وكذلك الثانية والثالثة والرابعة والخامسة فإذا كملت علامات الساعات فاجمعها[7] ثم ضع المصطرة على المركز وعلى غاية بقية البروج وعلّم على تقاطعها السادسة ثم مدّ خطًّا من ذلك الموضع إلى نقطة أوّل الربع فهي[8] مدارات البروج فاكتب أسماءهم وأعداد الساعات

<شكل> شكل ساعات الجنك لعرض لو

هذا الربع بخيطٍ واحدٍ

البـــاب ع في معرفة وضع هذه الساعات وتسمّى ساعات الشعبيّة D:90v P:12r

وهو أن تدير ربع دائرة وتربّعها بخطّين وتقسم قوس الربع ص قسمًا متساويًا ثم تمدّ خطوط مدار البروج كلّ منها[9] على الغاية خطًّا موازيًا لخطّ آخر الربع واكتب على كلّ مدار برجيه ثم ضع المصطرة على مركز الربع وعلى ارتفاع الساعة الأولى لكلّ مدار منها[10] وعلّم علامة[11] على كلّ منها[12] ثم ضع[13] المصطرة على المركز وعلى ارتفاع الثانية وعلّم أيضًا على كلّ منها[14] ثم ضع[15] المصطرة على ارتفاع الثالثة لكلّ مدار وعلّم أيضًا وكذلك الرابعة والخامسة فإذا كملت علامات الخمس ساعات فاجمعها[16] فهي[17] قسي الساعات وقوس الربع هو السادسة

<شكل> شكل ساعات الشعبية لعرض لو

وهذا الربع بخيطٍ واحدٍ

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[4] منهما P,D [5] هذه] تلك P [6] اضع P [7] فاجمعهما P,D [8] فهما P,D [9] منهما P,D [10] منهما P,D [11] علامة om. D [12] منهما P,D [13] اضع P [14] منهما P,D [15] اضع P [16] فاجمعهما P,D [17] فهما P,D

<شكل> ساعات زمانية لعرض لو

هذه الساعات بخيطٍ واحدٍ

D:89v P:11r **البـــاب سح في معرفة وضع هذه الساعات وتسمّى ساعات الوتر**

وهو أن[1] تدير ربع دائرة وتربّعها بخطّين وتقسم قوس الربع ص قسمًا متساويًا ثم اقسم خطّ أحد التربيع بستّة أقسام متساوية ومدّها[2] خطوطًا مستقيمة إلى أوّل قوس الربع فهي[3] مدارات[4] البروج فاكتب على كلّ مدار منها[5] <اسم> ذلك البرج ثم ضع رجل البركار في أوّل قوس الربع ورجله الأخرى على ارتفاع كلّ ساعة لرأس ذلك البرج وانقلها إلى المدار المطلوب وعلّم على كلّ مدار منها[6] لستّة علامات بقدر عدد الساعات الزمانية فإذا كملت[7] علامات الساعات لكلّ مدار منها[8] فاجمع تلك العلامات قوسًا إن أمكن وإلّا خطوطًا مقطّعة بالبركار كما تجمع ساعات البسيطة فإن لم يمكن جمعها[9] قسيًا[10] ولا خطوطًا فاجمعها[11] نقطًا واكتب عليها أعدادها وعدد العرض الذي رسمت له

<شكل> شكل ساعات الوتر لعرض لو

هذا الربع بخيطين — موضع الخيط الثاني

D:90r P:11v **البـــاب سط في معرفة وضع هذه الساعات الزمانية تسمّى ساعات الجنك[1]**

وهو أن تدير ربع دائرة وتربّعها بخطّين وتقسم قوس الربع ص قسمًا متساويًا ثم مدّ خطًّا وهميًّا من غاية الجدي إلى خطّ آخر الربع يكون موازيًا لخطّ أوّل الربع فموضع تقاطع هذا الخطّ لخطّ آخر الربع علّم علامة وخذ دون تلك العلامة من جهة المركز ومدّه خطًّا وهميًّا فهو مدار الجدي ثم اقسم ما بين مدار الجدي وبين نقطة آخر الربع ⌈ بنصفين ومدّه خطًّا وهميًّا ايضًا إلى نقطة أوّل الربع فهو مدار الحمل ثم مدّ خطًّا من نقطة أوّل الربع ⌉[2] إلى نقطة آخره فهو مدار السرطان ثم ضع المصطرة على المركز وعلى غاية كلّ منها[3] وعلّم على

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[1] وهو ذلك أن P [2] ومدهم P,D [3] فهما P,D [4] مدار D [5] منهما P,D [6] منهما P,D [7] تكملت P,D [8] منهما P,D [9] جمعهما P,D [10] قسي P,D [11] فاجمعهما P,D

[1] From Persian چَنگ harp, lute. [2] ⌈…⌉ om. D [3] منهما P,D

على غاية الحمل وأدره قوسًا فهو مدار الاعتدال وعلّم على كلّ[17] مدار ⌉ بقدر ارتفاع تلك الساعة وإن شئت فاقسم كلّ مدار منها[18] و̄ ⌈[19] <قسمًا متساويًا> وعلّم[20] في قوس الربع على كلّ عشرة <وعلّم أيضًا ستّ علامات في مدارين الحمل والجدي> فهو علامة الساعات فإذا كملت علامات الساعات على هذه المدارات فاجمعها[21] قسيًا[22] بالتقارب والتباعد فهي[23] قسي الساعات فاكتب عليها عددها وعرض البلد

<شكل> شكل الساعات المخصوصة لعرض ل̄

وهو بخيطين أحدهما في المركز والآخر في أوّل الربع — هذه النقطة موضع الخيط الثاني

البـــاب سز̄ في معرفة وضع هذه الساعات الزمانية لعرض مخصوص D:89r P:10v

وهو أن تدير ربع دائرة وتقسمها ص̄ قسمًا متساويًا ثم خذ فتحة بقدر الميل الأعظم وضع رجل البركار في المركز فأدر برجله الأخرى قوسًا فهو مدار السرطان[1] ثم اقسم ما بين مدار السرطان[2] وقوس الربع بنصفين وأدره قوسًا فهو مدار الاعتدال ثم ضع[3] المصطرة على غاية كلّ من المنقلبين وغاية الاعتدال وعلّم على ⌉ كلّ مدار منها[4] واجمعها[5] قوسًا فهو قوس الأفق ثم ضع[6] المصطرة على غاية كلّ برج من هاؤلا وعلى المركز وعلّم على ⌈[7] تقاطع المصطرة لخطّ الأفق ثم ضع[8] رجل البركار على كلّ علامة منها[9] وأدره قوسًا فهو مدار البرج الذي أردت ثم ضع[10] المصطرة على المركز وعلى ارتفاع كلّ ساعة وعلّم على تقاطع حرف المصطرة لمدار[11] ذلك البرج فإذا كملت علامات الساعات على سائر المدارات فاجمعها[12] قوسًا إن أمكن أو نقّطها[13] نقطًا[14] فقد كُمِل الوضع فاكتب على كلّ مدار اسم برجيه[15] وعلى قسي الساعات أعدادها واعلم أن قوس الربع هو مدار الجدي

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[17] كل om. **D** [18] منهما **P,D** [19] ⌈…⌉ marg. **P** (Since the margin is cut, only the upper half of the text is visible; also the *abjad* number و̄ at the end is not visible.) [20] ثمّ علّم **P,D** [21] فاجمعهما **P,D** [22] قسي **P,D** [23] فهما **P,D** [1] الجدي **P,D** [2] الجدي **P,D** [3] اضع **P** [4] منهما **P,D** [5] واجمعه **P** [6] اضع **P** [7] ⌈…⌉ om. **D** [8] اضع **P** [9] منهما **P,D** [10] اضع **P** [11] فلمدار **P** [12] فاجمعهما **P,D** [13] نقطهما **P,D** [14] فقط **P,D** [15] برجيه] برجه برجيه **D**

D:88r P:9v

بيان وضع ربع المقنطرات لعرض مح المحسوب له هذا الجدول الذي في ظهر هذه الورقة

وذلك أن تدير ربع دائرة وتربّعها وتدير دائرة المنقلبين كما تقدّم ثم تأخذ من الجدول ما بحيال كلّ مقنطرة وخذ بعدده من قوس الربع وضع عليه المصطرة وعلى المركز وعلّم على تقاطع حرف المصطرة لمدار[6] الذي أردت فإذا كملت علامات المنقلبين والاعتدال فاجمعها[7] قوسًا فهي تلك المقنطرة فإن بقي شيء من المقنطرات فاثبت رجل البركار في المركز وبرجله الأخرى على عدد كلّ مقنطرة من جهة الوتد وزدها بفتحته إلى جهة خطّ الزوال وعلّم علامات المقنطرات ثم اجمع تلك العلامات وعلامات المنقلب الأصغر يدار[8] رجل البركار على خطّ نصف النهار إلى أن تكمل المقنطرات

<شكل> شكل ربع المقنطرات لعرض مح

D:88v P:10r

البـــاب سو في معرفة وضع الساعات التي تكون[9] سادسها[10] وسع أولاها[11] وكلّها[12] وسع واحد

فإنّي لمّا رأيت أكثر الساعات المركّبة على الغاية أو ظلّ الزوال متضايق إلى أن تضيق السادسة والخامسة ولم تبعد منهما[13] شيء يسير لا يكاد يتقسّم بين الساعتين[14] ولا تُعلَم فاستنبطت هذه الساعات لكي تفيق على ساعات جنسها وتكون كلّها وسعًا واحدًا[15]

فإذا أردت ذلك فأدر ربع دائرة وربّعها ثم اقسم خطّ التربيع ص[16] ثم ضع رجل البركار في أوّل قوس الربع ورجله الأخرى على المركز وأدر به قوسًا وهي فتحة نصف القطر ثم انقله حتى تضعه في المركز ورجله الأخرى على غاية رأس الجدي من قسمة خطّ التربيع وأدره قوسًا فهو مدار الجدي ثم ضع رجله

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[6] الحدار **D**; the words الحدار and المدار are superimposed in **P**, the latter probably being a correction of the former. [7] فاجمعهما **P**,**D** [8] مدار **P**,**D** [9] الذي يكون **D**; الذي تكون **P** [10] سادسها **P**,**D** [11] أولتها **P**,**D** [12] وكلها **P**,**D** [13] منهما om. **D** [14] الساعة **P**,**D** [15] وسع واحد **P**,**D** [16] ثم اقسم خطّ التربيع ص marg. **P**

المذكور فاخترت أن أضع لها[2] هذا الربع ليبيّن فساد ما ذكروه واستعملوه من قديم الزمان إلى هذا التأريخ فإنّ هذا الشكل يُظهِر الفساد أكثر من ستّة عشر درجة

⌈ **بيانه** إنّ ارتفاع يز لرأس السرطان دائره كح لح[3] ودائره في رأس الجدي مب ه فبينها يو كز ⌉[4] فإنّ الربع الذي يكون أقلّ عرضًا[5] من مح كان أقلّ فساد من هذا فأردت الأكبر لعلّ (؟) أن يرجعوا عن ما ثبت في أذهانهم لعرض ل الذي هو مشهور وقد أظهرت فساده في الدرجة أو درجة ونصف

فإذا أردت وضع هذا الربع فهو الشمالي الأوّل المتقدّم ذكره فما يحتاج أن نعيد صفة الوضع وإنّما أردنا أن نغيّر الشكل بعرض آخر وينبغي أن نستخرج لهذا العرض جدولًا من جداول الدائر كما استخرجنا جدول المقنطرات لعرض لو وهو هذا

جدول وضع المقنطرات لعرض مح شمال وجنوب									
سرطان				حمل				جدي	
عدد المقنطرات	فضل الدائر	مقنطرات	فضل الدائر	عدد المقنطرات	فضل الدائر*	مقنطرات	فضل الدائر*	مقنطرات**	فضل الدائر*
د	قيط و	لو	سا لط	د	ص د	لو	كح لد	د	س ند
ج	قيج لط	لط	نز كا	ج	فه ل	لط	يط نا	ج	ند ز
و	قح كد	مب	نب ما	و	ف نط	مب [a]	د د	و	مط ا
ط	قج كا	مه	مح ه	ط	عوكو			ط	مب ه
يب	صح كز	مح	مج لط	يب	عا يج			يب	لد يو
يه	صج م	نا	لح مب	يه	سز يو			يه	كد د
يح	فط د	ند	لج لج	يح	سب لج			يح	ي د
كا	فد ك	نز	كح ط	كا	نط يه				
كد	عط مح	س	كب يا	كد	نب لا				
كز	عه يط	سج	يد نب	كز	مز كد				
ل	ع مط	سه له	د د	ل	ما ما				
لج	سو يح			لج	له له				

D م [a] D مقنطرات del. and corr. to فضل دائر ** P,D فضل دائر] فضل الدائر *

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[2] لهما **P**,**D** [3] دائره طح لح **D**; illeg. **P** (upper margin cut off) [4] ⌈…⌉ marg. **P**; ـها يو كز illeg. **P** [5] عرض **P**,**D**

البركار موضع تقاطع الأفق لخطّ مدار تلك الغاية فحيث وقعت رجله الأخرى على ذلك المدار فهو موضع الساعة فإذا كملت الساعات كلّها فاجمعها

جدول ظل الساعات منكوس							
غاية الارتفاع	ا	ب	ج	د	ه	و	عصر
	ظل منكوس	ظل منكوس	ظل منكوس	ظل منكوس	ظل منكوس	ظل منكوس	ظل منكوس
ي	ۮ كا	ا ج	اكح	امح	ب ج [d]	ب ز	ب ا
ك	اا	ب ه	ب نح	جمج	د يا	دكب	جيب
ل	ال	جو	دكط	ه يو	ولز	و نو	دكج
م	انز [a]	جن	و ج	ح د	ط لا	ي د	ه كط
ن	ب كا [b]	د نط [c]	زلح	يا ط	يجيه	يد يط	و لب
س	ب لط	ه مو	ط ط	يجلح	يح كا [e]	ك مز	ز نج
ع	ب ند	وكج	يكح	يز ن	كو و	لب نح	ح مز
ف	ب نز	و ل	ياكد	يط لط	لز يط [f]	سح جه	يۮ
ص	جو	و نو	يبۮ	ك مز	مد مز	ۮ ۮ	يبۮ

[a] ا نر (or نز) **P**; ا بر **D** [b] ر كا **D** [c] د ىط **D** [d] ب خ (!) **P**; ب خ (!) **D**
[e] مح كا **D** [f] كز ىط **D**

<شكل> شكل ساق الجرادة[11] والمكحل
مكان المري المتحرّك[12] — طول الشخص — قوس الزوال آفاقي للبلاد المسكونة[13] آفاقية للأقاليم[14] السبعة للشمس خاصّة تقريبًا

D:87v **P**:9r
البـــاب سه في معرفة وضع ربع المقنطرات لعرض مح

وهو آخر البلاد المسكونة وذلك لمّا رأينا أرباب هذا الفنّ يعملوا الدائر للارتفاع إذا كان أقلّ من ارتفاع القطر وخرج الخيط عن الربع من جهة النظير في الربع الموضوع لعرض ل وذلك خطأ كبير من الجهلة المستعملين[1] بهذا

[11] الساق جرادة **P,D** [12] المتحركة **D** [13] قوس الزوال آفاقي للبلاد المسكونة om. **D** [14] الأقاليم **D**
[1] المستعملون **P,D**

<جدول>[4]

غاية	ا	ب	ج	د	ه	و	عصر
ي	قفجـ نجـ [a]	قلز ح	صزمه	عح نو	ع كو	سح جـ	ف جـ
ك	قم لب	سطكجـ [e]	مح مد	لح مز	لد كه	ل نح	مد نح
ل	صه يز [b]	موكه	لب و	كد نز	كا مجـ	ك نز	لب مز
م	عجمجـ	لزلا	لجـمط	يز نجـ	يه و	يد يط	كو يط
ن	سا لب [c]	كح نجـ [f]	يح نجـ	يب ند	ي نجـ	ي جـ	كب د
س	ند ط [d]	كد نح	يه مد	يلجـ	ز نا	و نو	يح نو
ع	مط لط	كب لب	يجـمه [h]	ح لجـ	ه ل	د ي	يوكب
ف	مح نط	كب ز	يبلح	ز ك	جـ نب	ا ند	يجـ ند
ص	موكه	كا مز [g]	يب ذ	و نو	جـ يجـ [i]	—	يب ذ
	ظل الساعات						ظل العصر

جدول ارتفاع العصر	
ي	ح لا
ك	يد نو
ل	ك و
م	كد ل
ن	كح لجـ
س	لجـ يز
ع	لو يجـ
ف	م مط
ص	مه ذ

[a] فقجـ نجـ **P,D** [b] صه ن **D** [c] لب in **P** looks like ل ; سا ل **D** [d] نب ط **D** [e] سطكح **D**
[f] كح نح **D** [g] Should be 20;47 [h] يح مه **D** [i] حـ نجـ **D**

البـــاب سد في معرفة وضع ساعات المكحل وساق الجرادة[5] الآفاقية لسائر العروض المسكونة تقريبًا **D**:87r **P**:8v

وذلك أن تستخرج لهما جدولًا كما تقدّم واثبت[6] ارتفاع الساعات وتأخذ من جدول الظلّ المحلول ظلّ ذلك الارتفاع منكوسًا وصوّره جدولًا لوقت الحاجة ثم اتّخذ لوحًا[7] من خشب مصطحي[8] الجسم أو مكحل مدوّر واقسم كلّ منها عشرة أقسام ومدّها[9] خطوطًا مستقيمة واكتب عليها عدد الغاية ثم اقسم مدار غاية فط بقدر[10] ظلّ السادسة منكوس واعمل منه مصطرة وطول الشخص من تلك المصطرة يب وخذ فتحة بقدر ظلّ كلّ ساعة منكوس واثبت رجل

[4] The sixth column for the midday shadow is set in both manuscripts at the *right* of the arguments. Moreover, in **D**, the entries for hours 2 to 4 for $H = 20$ have been repeated in the row $H = 30$, and the two consecutive rows also have the entries for the preceding argument. The copyist has noticed this slip and has consequently crossed-out the three repeated entries in the third row; he then drew a line leading to three small replacement cells underneath the table, in which he wrote the three missing entries, overlooking the fact that these missing entries belong in fact to the *fifth* row! [5] (!) **الساق جرادة** **P,D** [6] وثبت **P,D** [7] لوح **P,D** [8] مصطحب **P,D** [9] ومدهم **P,D**
[10] بقدره **P,D**

<شكل> شكل البسيطة الآفاقية لسائر العروض المسكونة وذلك من بلد لا عرض له إلى عرض مح تقريبًا

خطّ الزوال — مركز الشخص — طول الشخص — قوس العصر

D:86v
P:8r

البـــاب سج في معرفة وضع الساعات الآفاقية لسائر العروض المسكونة

وذلك من عرض د د إلى عرض مح للشمس خاصّة تقريبًا المركّبة على غاية الارتفاع إذا أردت ذلك فاعلم الغاية ثم استخرج ارتفاع الساعات لتلك الغاية كما تقدّم من باب سا المتقدّم ثم ادخل بذلك الارتفاع جدول الظلّ المحلول دقيقة دقيقة وخذ ما بحياله فهو ظلّ تلك الساعة وأمّا ارتفاع العصر فزد على ظلّ الزوال قامة فهو ظلّه ثم ادخل بظلّ العصر في الجدول أيضًا وخذ ما بحياله من عدد الارتفاع فهو المطلوب فاكتبه جدولًا وهذه الساعات توضع قارة في الربع من خشب أو غيره أو دائرة كاملة إذا أردت ذلك فأدر دائرة واقسمه[3] ص ومدّ خطًّا شعاعيًا من تلك الغاية الذي تريد إلى المركز فهو مدار تلك الغاية ثم اقسم نصف القطر بقدر ظلّ الساعة الذي تريد وضعها فهو مصطرة الوضع وطول يب هو قدر الشخص ثم خذ فتحة بقدر ظلّ كلّ ساعة واثبت رجله في مركز الربع والأخرى حيث وقعت على مدار تلك الغاية فإذا كملت الساعات فافعل بالعصر كذلك فقد كُمِل الوضع

<شكل>

[3] واقسمها P

خمسة أقسام من الستّة فهو المدار المركّب على ظلّ زوال وَ أصابع ثم ضع رجله في خطّ نصف النهار وتباعد وتقارب حتى تجمع علامتي كلّ من المدارات فظلّ زواله قوسًا فهو المطلوب

<**شكل**> شكل البسيطة الآفاقية لسائر العروض المسكونة تقريبًا وذلك من بلد لا عرض له إلى عرض مح

<**ملاحظة**> فإن أردت قوس العصر فخذ فتحة بالبركار بقدر ظلّه وضعه[19] في المركز والأخرى على مدار ظلّ الزوال واجمعه قوسًا[20] والله أعلم

الباب سب في معرفة وضع الساعات الزمانية المركّبة على ظلّ الزوال بوجه آخر

D:86r

وهي التي عُمِلت[1] على جنب الميزان الفزاري لأنّ مدارات ظلّ الزوال مستقيمة فأردنا أن نبيّن شكلها عن الشكل المتقدّم وهو أحسن التركيب لأنّ المدار إذا لم تخرج الجهة فلا فرق أن يكون مستقيمًا أو مستديرًا بل إذا كان مستقيمًا كان أحسن من المستدير فالذي تقدّم وضعه تُعلم منه الساعات ولا يمكن أن تُعلم منه الجهة فإنّ الجهة تكون لبلد مخصوص وهذه مخصوصة بالشمس لسائر العروض المسكونة تقريبًا يسيرًا

فإذا أردت ذلك فاقسم عرض الرخامة أو غيرها بنصفين ومدّه خطًّا فهو خطّ الزوال ثم اقسم خطّ الزوال بقدر لو قسمًا وهو ظلّ زوال أكثر الجداول واجعله مصطرة ثم مدّها[2] خطوطًا مستقيمة ثم خذ من جدول ظلّ الساعات بقدر ظلّ ساعة وضع رجل البركار في المركز والأخرى على المدار الذي أخذت ظلّه وعلّم عليه برجله الأخرى من جهة اليمين واليسار فإذا كملت علامات الساعات فاجمعها واكتب على كلّ ساعة عددها وعلى كلّ مدار ظلّ زواله المعلوم فقد كُمِل المدارات فإن أردت قوس العصر فخذ فتحة بالبركار بقدر ظلّه المبسوط وضع رجله في المركز والأخرى حيث وقعت على مدار ظلّ الزوال فاجمعه قوسًا

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[19] ضعه] اضعه **MS** [20] قوسا] قوس **MS** [1] عملى or فعلى **MS** [2] مدهما **MS**

فإذا أردت وضع هذه الساعات الزمانية فاتّخذ لوحًا[15] من خشب أو رخامة وأدر ثُلثَي دائرة وربّعها بخطّين الخطّ الأوّل يقطع القوس بنصفين والآخر يقاطع هذا الخطّ على زوايا تمرّ بالمركز ثم اجمع من طرفي ذلك القوس والمركز فهو مدار بلد لا عرض له ثم خذ من جدول الظلّ ما بحيال الظلّ د د بجيب الأولى[16] من الظلّ فاحفظه ثم اقسم نصف قطر الدائرة بقدر أطول ظلّ تلك الساعة التي[17] تريد أن تدخل بها الرخامة خذ من تلك القسمة يب فهو طول الشخص فاجعل منه مصطرة ثم خذ بقدر ظلّ الساعة المحفوظة أوّلًا من قسمة المصطرة فضع رجل البركار في المركز والأخرى حيث وقعت على مدار بلد لا عرض له فهي علامة تلك الساعة ثم اجمع المدار المركّب على ظلّ زوال لو وهو مدار نهاية العروض المسكونة وهو عرض مح ثم خذ فتحة بقدر ظلّ بقية الساعات وضع رجل البركار في المركز والأخرى حيث وقعت على كلّ من المدارين وهما أوّل المدارات وآخرها واجمعهما فهي[18] الساعات المطلوبة وإن كانت الساعة الأولى لا يمكن وقوعها على المدار المركّب على ظلّ زوال لو فاستخرجه لمدار يمكن وقوعه على طرف هذا الدائرة فقد كُمِلت الساعات الزمانية وأمّا الساعات المستوية فلا يمكن أن ترسم على ظلّ الزوال D:77v

وأمّا المدارات فضع رجل البركار بفتحة نصف القطر في موضع تقاطع خطّ الزوال للدائرة واضرب برجله الأخرى على تلك الدائرة من الجهتين فهو المدار الأصغر المركّب على ظلّ زوال لو ثم اقسم ما بين المدار الأكبر والأصغر بنصفين ومدّ خطًّا مستقيمًا فهو المدار الأوسط المركّب على ظلّ زوال يح ثم اقسم ما بين المدار الأوسط والأصغر بثلاثة أقسام فهما المدارين أحدهما مركّب على ظلّ زوال ل والآخر على ظلّ زوال كد ثم اقسم ما بين المدار الأوسط والأكبر بستّة أقسام وخذ من جهة الأوسط بقدر ثلاثة أقسام من هذه الستّة فهو المدار المركّب على ظلّ زوال يب ثم خذ من تلك القسمة من جهة الأوسط بقدر

[15] لوح MS [16] الأولة MS [17] الذي MS [18] فهما MS

جدول ظلّ الساعات من بلد لا عرض له إلى عرض مح تقريب للشمس خاصّة وهي التي تركّب على الموازيين

ظل الزوال	ا	ب	ج	د	ه	عصر
ۮ	مد مز	ك مز	يب ۮ	و نو	جـ يجـ	يب
ب	مح نه	كا ي	يب لد	ز يد	جـ مو	يد
د	مط نه	كب ز	يجـ لد	ح كد	ه يجـ	يو
و	نب له	كد ه	يه ۮ	ط نا	و نط	يح
ح	نو نح	كو يح	يو مو	يا لا	ح نا	ك
ي	سا مد	كح نجـ [c]	يح ن	يجـ نب	ي ن	كب
يب	سزا	لا مب	كا ه	يد كه	يب مط	كد
يد	عب مز	لد نجـ	كجـ كح	يز لد	يه ب	كو
يو	عط ه [a]	لح ي	كو ۮ	يط مد [e]	يو ن	كح
يح	فه مه	مالجـ	كح نو	كا نه	يح نجـ [f]	ل
ك	صب ما	مد نجـ [d]	لا ح	كد ز	ك نو	لب
كب	صط مه	مح لا	لجـ لجـ	كو ك	كب ند	لد
كد	قو مط	نب يط	لو يز	كح لجـ	كه ۮ	لو
كو	قيه لا	نو كح	لط جـ	ل مو	كز يد	لح
كح	قكجـ يب	س لجـ	ما نا	لجـ ۮ	كط م	م
ل	قكح يط	سد ح	مد مز	له و	لا يب	مب
لب	قلو يو [b]	سح نح	مز يد	لز لو	لجـ يجـ [g]	مد
لد	قمد ه [b]	عجـ ط	ن ۮ	لط مح	له كا	مو
لو	قمط ما	عز ي	نجـ ۮ	مب ه	لح ه	مح

[a] ه (!) عما **D** [b] illeg. **P** [c] يجـ كح **D** [d] نجـ مه corr. to نجـ مد **P**; يجـ مه **D** [e] يه مد **D** [f] نجـ مح **P**; يجـ مح **D** [g] يجـ written like يحـ **P**,**D**

ظلّ تلك الساعة فاستخرجنا له هذا الجدول لمن أراد أن يضع هذه الساعات المذكورة فافهم تصب

جدول ارتفاع الساعات من بلد لا عرض له إلى عرض مح تقريب للشمس خاصّة وهي تُعلم على ساق الجرادة[14]

ظل الزوال	ا	ب	ج	د	ه	و	عصر
ء	يه ء	ل ء	مه ء	س ء	عه ء	ص ء	مه ء
ب	يج مز	كط لج	مج ما	نح نو	عب لج	ف لو	م لز
د	يج ل	كح كح	ما لط	نه ب	سو لا	عا لد	لو نا
و	يب نا	كو كح	لح لو	ن لج	نط مط	سج كد	لج ما
ح	يا ند	كد لج	له ل	مو ي	نج لد	نو كد	ل نه
ي	يا ء	كب لب	لب كز	م نج	مز نه	ن ي [f]	كح لز
يب	ي ط	ك مب [b]	كط لح	لز مز	مج و	مه ء	كو لد
يد	ط كب [a]	يط ء	كز و	لد كا	لح له	م لز	كد مز
يو	ح لح	يز كح	كد مح	لا ك	له كز	لو نب	كج يد
يح	ز نح	يو و	كب ل	كح نو	لب كه	لج ما	كا مز
ك	ز كج	يد نح [c]	كا د	كو كز	كط مز	ل نو	ك لب
كب	و ند	يج ن	يط م	كد لا	كز م	كح لز	يط كو
كد	و كه	يب نه	يح يح	كب مه	كه لح	كو لد	يح كو
كو	ه نو	يب ء	يز ه	كا يح	كج مز	كد مز	يز لب
كح	ه لد	يا يج	يو ء	يط نح	كب ج	كج يد	يو ما
ل	ه كا	ي ل	يه ء	يح مح	كا ب	كا مز	يه نو
لب	ه ب	ط نب	يد يو [d]	يز مد	يط ن	ك لب	يه يو
لد	د مو	ط ك	يج ل	يو مو	يح مو	يط كو	يد لو
لو	د له	ح ن	يب مه	يه ند [e]	يز ل	يح كز	يد ب

[a] ط ي D [b] كب مب P,D [c] يد يح D [d] يد نو D [e] يه يد D [f] نه ي D

14 ساق الجرادة] الساق جرادة P; this caption is lacking in D

فمن أراد أن يستمحن ما ذكرناه من الجداول والوضع ولا له يد ولا قدرة على جداول النسب المذكورة أوّلًا فعليه بهذه الآلة فإنّها تقرّب له جميع ما يطلبه ولا سيّما أن تكون دائرة كبرى وهذه صفته ومن زاد على هذا الوضع فقد بعد عن الضرورة ويظلمه وإنّما ينبغي أن تكون عليه عضادة مركّبة مقسومة س جزءًا متساويًا

<شكل> <شكل الدستور>

الربع الشمال الشرقي — الربع الشمالي الغربي — الربع الجنوبي الغربي — الربع الجنوبي الشرقي[4]

البـــاب سا في معرفة وضع الساعات المركّبة على ظلّ الزوال المخصوصة بالشمس خاصّة وببعض العروض وهي[5] السبع الأقاليم المسكونة وذلك من بلد لا عرض له إلى عرض مح D:77r P:7v

فإنّي باشرتها بعمل (؟) السهم[6] والجيب فوجدت فيها تقريبًا يسيرًا فأخترت ذلك أن أضعه في كتابي هذا لكبر صعوبة الساعات بالسهام وكان يُلزِمنا أن نغيّر (؟)[7] كلّ عرض ونكتبه على شكل الوضع فكان يطول الشرح في ذلك فلمّا نظرنا أن هذه الساعات فيها تقريبًا يسيرًا[8] ومنفعتها[9] عامة كثيرة[10] فعملتُ تلك الغاية لظلّ الزوال من جدول الظلّ المحلول

وأخرجنا ارتفاع الساعات من ربع الساعات المرسومة في الباب[11] نز أو من جهة الحساب التقريب أن تأخذ جيب الغاية ثم تأخذ ربعها فهو جيب[12] ارتفاع أ ونصف جيب الغاية فهو جيب ارتفاع ب ونصف جيب الغاية وخمسها فهو ارتفاع ج وثلثي جيب الغاية وخمسها فهو جيب ارتفاع د ثم تنقص من جيب الغاية ثُلث عُشرها فهو جيب ارتفاع ه فتزيد على ظلّ الزوال يب فهو ظلّ العصر ثم تقوّس جيب ارتفاع الساعات فهو ارتفاعها المطلوب ثم تدخل بارتفاع كلّ ساعة منها[13] في جدول الظلّ وخذ ما بحياله من درج ودقائق فهو

[4] Text om. **D** [5] وهما **P,D** [6] السهام **P,D** [7] نعر **D**; نعر **P** (with two dots under and over the above and under the line, respectively. [8] يسير **P** [9] ومنفعتهما **P,D** [10] عامًا كثيرًا **D**; عامًا كثير **P** [11] الباب] باب **D** [12] **P,D** (! ـ [13] منهما **P,D**

يُقسم جنبها دقيقة دقيقة لأخذ الارتفاع فلمّا كان كتابنا هذا لا غناء له عن الارتفاع وقد ركّبته على الغاية فاحتجنا إلى آلة صحيحة يؤخذ منها الارتفاع دقيقة دقيقة فلم نجد أوفق من هذه

فإذا أردت وضعها فاتّخذ قائمتين[13] من خشب[14] مصطحيتين[15] على زوايا قائمة ليكون نهاية فتحتها بقدر[16] وتر ربع الدائرة[17] وقد وضعنا لها وترًا مقسومًا وهو فد ن دقيقة تقريبًا لنأخذ به الارتفاع ثم قسمنا أحد القائمتين بقدر الجيب الأعظم مركّبًا على قوس الربع لنأخذ الارتفاع أيضًا ولها هدفتان[18] كالعضادة لدخول الظلّ فإذا ذخل الظلّ نطرنا إلى خيط الشاقول على[19] كم وقع الضلع[20] الثابت فهو الارتفاع وإن شئنا ألزقنا ضلع[21] الوتر لطرفي الآلة فما قطع طرفها من قسمة الوتر فهو الارتفاع المأخوذ في ذلك الوقت

<شكل> صفة القائمة المتحرّكة كالبركار وهذا نهاية قيامها والارتفاع يومئذٍ[22] ص

الشاقول إذا كان الارتفاع ص — صفة خيط الشاقول إذا كان الارتفاع س — الشاقول إذا كان الارتفاع س[23] — صفة قائمة القطر

البـــاب س في معرفة وضع الدستور

D:76v
P:7r

أدر[1] دائرة وربّعها ثم اقسم الدائرة شس قسمًا كلّ ربع منها ص قسمًا متساويًا ومثلتُ أنّ الدائرة هي دائرة الاعتدال ببلد لا عرض له فأخذت الدائر بقدر ارتفاع خمسة فوجدته مطابقًا للارتفاع فمددت خطوطًا مستقيمة ثم كلّ منها[2] على خطّ التربيع وهما الجيوب المبسوطة والمنكوسة وما شئتُ وضع هذه الآلة في كتابنا هذا إلّا لكون إنّها آلة شريفة قديمة رحمة اللّه على من صنعها فإنّها[3] يغني عن الحساب لمن لا له يد في الضرب والقسمة وهو أقرب إلى الصواب من غيرها

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[13] قائمتان **P,D** [14] من خشب marg. **P** [15] مصطحيتان **P,D** [16] بقدر marg. **P**; om. **D** [17] وتر ربع الدائرة] وتر الربع الدائر **D**; وتر الربع الدائرة **P** [18] هدفتين **P,D** [19] علم **D** [20] الطلع **D** [21] طلع **D** [22] يومئذ om. **P** [23] ص om. **P** [1] أدر] اد **D** [2] منهما **P,D** [3] فإنه **P,D**

D:75v
P:6r

البـــاب نح في معرفة وضع الربع المجيّب وهو أشرف الأرباع الآفاقية وأحسنها وأقربها إلى الهيئة[1] وهو خاتمة أرباع الأعمال

إذا أردت ذلك أدر قوسًا واقسمه ص جزءًا متساويًا[2] ثم اقسم خطّ أوّل الربع س قسمًا متساويًا ثم اعلم من جدول الجيوب ما يخصّ جيب خمسة خمسة أو غير ذلك وخذ بمثله من تلك القسمة وضع المصطرة عليه وعلى قوس ذلك الجيب ومدّه خطًّا مستقيمًا إلى قوس الربع فهي[3] الجيوب المبسوطة ثم ضع رجل البركار في مركز الربع والأخرى على كلّ قسم من الجيوب المبسوطة وأدر برجله إلى الخطّ وعلّم علامات ومدّها[4] خطوطًا مستقيمة إلى قوس الربع فهي[5] خطوط الجيوب المنكوسة

وإن شئت بطريق الهندسة فضع رجل البركار في المركز وتقسم خطّ أحد الربع[6] بنصفين وأدر ربع دائرة ثم ضع المصطرة على المركز وعلى أقسام قوس الربع ومدّ خطًّا شعاعيًا إلى ذلك القوس فإذا كملت خطوط الأشعّة ضع رجل البركار في موضع تَقاطُع تلك الدائرة للخطّ الشعاعي واضرب برجله الأخرى على كلّ من جهتين فإذا كملت العلامات فضع المصطرة على كلّ منها[7] وعلى كلّ خمسة من قوس الربع ومدّها[8] خطوطًا مستقيمة إلى قوس الربع من جهة اليمين واليسار فقد كُمِلت الجيوب المبسوطة والمنكوسة وافهم تصب

<شكل> شكل الربع المجيّب[9]

D:76r
P:6v

البـــاب نط في معرفة وضع ذات الشعبتين

وهي آلة رصدية لا سيّما في زماننا هذا فإنّ الآلات التي يُرصد بها كلفة مثل ذات الحلق وغيرها من آلات[10] القدماء يحتاج مع ذلك إلى همّة وإمكان وهذه الآلة خفيفة الثمن قليلة الخطوط ليس فيها غير قسمة على جنبها الواحد والآخر يرتفع وينخفض صفة البركار وقد تُعمل لها قوائم ولوالب[11] تقوم عليه[12] وقد

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[1] هئة **P,D** [2] متساوية **D** [3] هي] هم **P,D** (on **P** first written هم but then prolonged with a ي so that it resembles هي [4] مدها] مدهم **P,D** [5] هي] هما **P,D** [6] الربع] التربيع **D** [7] منهما **P,D** [8] ومدهما **P,D** [9] شكل ربع المجيب **D** [10] الآلات **P,D** [11] لولب **P** [12] عليه om. **D**

D:75r
P:30v

البـــاب نز في معرفة وضع الساعات الآفاقية

وهو أن تدير ربع دائرة وتربّعها بخطّين ثم تقسم قوس الربع ص قسمًا متساويًا ثم ضع رجل البركار على خطّ آخر الربع وتتقدّم وتتأخّر حتى تجمع القطب وعدد تلك الساعة وهو يه بفتحة بالبركار وكذلك إلى أن تُنهي الساعات الستّة ثم تفعل ذلك بأقسام الساعات إمّا خمسة <خمسة> أو ثلثة ثلثة وتكتب بين قسي الساعات أعدادها ⌈ فهي[1] أصل لبعض الأعمال ⌉[2] وإن شئت أن تجمع الساعات بغير تقارب وتباعد فخذ فتحة القطر كاملًا[3] وهو قك[4] للأولى[5] وفتحة نصف القطر وهو[6] س للثانية وفتحة نصف وتر الربع وهو مب كه للثالثة وفتحة وتر خمس الربع[7] وهو لز د للرابعة وفتحة وتر سدس الربع وهو لا د للخامسة وفتحة ربع القطر وهو ل للسادسة وأدر لكلّ فتحة معلومة من عدد تلك الساعة إلى مركز الربع

وهذه الساعات إذا وضعت كما تقدّم من غير أن تدخلها خطّ آخر أو قوس آخر كانت[8] آفاقية لسائر الآفاق المسكونة وهم[9] السبع الأقاليم وذلك من عرض ﺪ ﺪ إلى عرض مح للشمس خاصّة تقريبًا جيّدًا فإنّ الساعات الآفاقية التي تعمل في سائر الآفاق المسكونة أو غير مسكونة للشمس والكواكب فلا[10] يمكن عملها إلّا بشيء آخر بداخلها إمّا من جنس الجيب أو من جنس الحساب فوجدت هذه بمفردها يستغني بها من أراد العمل بها وسوف تأتي رسالتها ممّا (؟) تضمنه (؟)[11] <من> (؟) الأعمال بالتقريب

<شكل> ساعات زمانية آفاقية[12]

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[1] فهم P,D [2] ⌈…⌉ : فهم أصل لبعض الأعمال marg. P [3] باملا D [4] قك] فط D [5] للاوله P,D [6] وهو نصف القطر وهو marg. P; وهو om. D [7] خمس الربع] الخمس الربع D [8] كانة om. D [9] هما P,D [10] فلا] لا P,D [11] تضّمنه P; تصمنه D [12] Caption om. P

الباب نو في معرفة وضع الربع المجنّك[9] D:74v P:30r

وهو أن تدير ربع دائرة وتربّعها بخطّين ثم خطّ بين ذلك الخطّين بالجيوب المبسوطة والمنكوس بعدّ قسمة أحد الخطّين س وتأخذ من القسمة بقدر <تمام جيب> نصف فضلة أحد المنقلبين وتضع رجل البركار في المركز والأخرى تحت المركز ليكون جملة ذلك البعد بقدر <سهم> نصف قوس النهار الأطول ثم ضع رجله في آخر القوس والأخرى على سهم نصف قوس السرطان وانقلها إلى خطّ الجيب الموافق لجيب الغاية لرأس السرطان وكذلك تفعل لرأس الأسد والسنبلة والميزان فعلّم[10] على كلّ مدار منها موضع الموافقة ومدّه خطًّا إلى نقطة[11] آخر الربع واعمل أنّها أربع مدارات مدار واحد للمنقلبين والثاني للاعتدالين والثالث لرأس كلّ برج ميله يا لب دقيقة والرابع لرأس كلّ برج ميله ك يو دقيقة فاكتب على كلّ مدار ما يحصّه من البروج ثم ضع رجل البركار في نقطة آخر الربع والأخرى موضع الموافقة وأدر قوسًا إلى الجيب المقسوم ثم أدر تلك القسي إلى خطّ الجيب إن شئت خمسة أو ستّة ستّة أو درجة درجة وهو أحسن الوضع

وإن شئت فاجعله ربعًا بغير زيادة نصف الفضلة وإنّما تعمل فيه قوس الأفق وذلك أن تضع رجل البركار على خطّ الجيب الستّيني من تحت المركز والأخرى على موضع موافقة المدار لجيب غايته وعلى عدد نصف الفضلة من عدد الجيب مبتدئاً من مركز الربع وأدر برجله قوسًا إلى خطّ الجيب الستّيني

فقد كُمِل الوضع

<شكل> شكل الربع المجنّك لعرض لو

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[9] From Persian چَنگ harp, lute. Cf. Ch. 69. [10] فعلّم] يعلم D [11] نقطة] مركز P,D

وإن شئت ما تحتاج إلى هذا الجدول فإنّ الجدول الأوّل يغني عنه

D:74r
P:34v

البـــاب نه في معرفة وضع الربع المستّر

وهو مقنطرات شمالية مركّبة على مقنطرات جنوبية فإذا أردت وضعه فهو كما وضعت مقنطرات الربع الشمالي والربع الجنوبي لكن قوس الربع هو مدار الاعتدال وإن شئت فعلّم على قوس الربع بقدر سعة المشرق لذلك[1] البعد المكتوب في الجدول

ثم أدر دائرة السرطان وهمية وعلّم عليها بقدر الدائر لذلك البعد الذي أردت ثم ضع رجل البركار على خطّ الربع وتتقدّم أو تتأخّر حتى تجمع العلامات الحمل والسرطان واعلم أنّ سعة مشارق البعد هو الدائر لارتفاع الحمل فإن شئت أن تضع بالجدول ولا يحتاج إلى سعة المشارق وتضع[2] من[3] الجدول الأوّل وجدول سعة المشارق لعرض لو فإذا تكمّلت علامات السرطان فافعل بالمقنطرات الشمالية كما تقدّم ثم اجمع بين علامات المقنطرات واثبت[4] رجله على خطّ آخر الربع فقد كُمِلت المقنطرات فإن بقي منها[5] شيء من الجنوبية فاجمع بقيّة علامات سعة المشارق مع علامات المقنطرات الشمالية واكتب عليها أعدادها وكذلك درج قوس الربع إلى ص وهذا الربع هو[6] أحسن الأرباع المخصوصة بالعروض فإنّه لا يحتاج إلى غيره وليس فيه مدارات مرسومة لينعكس الشمالي جنوبي والجنوبي شمالي كما تقدّم في وضع الأرباع

<شكل> شكل الربع المستّر لعرض لو

<ملاحظة> هذا القوس جميعه مقسوم[7] ص وإنّما الوضّاع سها فجهله اكثر وهو غلط[8]

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[1] لذالك **P** [2] أو تضع **P,D** [3] من om. **D** [4] وثبت **P,D** [5] منهم **P,D** [6] هو om. **P** [7] مقسومة **D**; (note that قوس can be masculine or feminine, but in this text it is masculine throughout).
[8] This remark is written by copyist C3.

برجله علامة ثم انقله حتى تضع رجله على خطّ مشرق[10] دائرة أوّل <فضل> الدائر ورجله على كلّ علامة وأدر قوسًا متّصلًا بطرفي الدائرة وقطب معدّل النهار وهو المكتوب عليه عرض البلد فهي[11] قسي <فضل> الدائر[12] وتفعل ذلك من جهتي[13] اليمين واليسار حتى تُكمل علامات الاعتدال

فاعلم دائرة من دوائر الارتفاع الأعلى والادنى وضع رجله موضع تقاطع قوس أوّل <فضل> الدائر لتلك الدائرة ورجله الأخرى على قوس من <فضل> الدائر على مداره وانقل تلك الفتحة على ذلك <فضل> الدائر من الجهة الأخرى وعلّم علامات واجمعها[14] كما تقدّم فقد كملت قسي <فضل> الدائر فاكتب عليه عدده

<**شكل**> شكل المساترة اللّيلية لعرض لوَ

البعد عن الاعتدال	جدول وضع المساترة لعرض لوَ	
	سعة المشرق	
	درج	دقائق
ي	يب	كج
ك	كه	د
ل	لز	لط
م	نا	نح
ن	ع	كد
	أبدى الظهور	
	أعلى	أدنى
س	سو	و
ع	نو	يو
ف	مو	كو
ص	لو	لو

[10] على خطّ مشرق om. **D** [11] فهما **P,D** [12] الدائرة **D** [13] جهة **D** [14] واجمعهما **P,D**

فإن أردت <قسي فضل> الدائر فاعلم ما يخصّ <لفضل> الدائر[8] خمسة خمسة أو غير ذلك من الارتفاع الذي في الجدول وعلّم بمثله في المقنطرات على المدارات الثلاث ثم ضع رجله على قوس أوّل <فضل> الدائر ورجله الأخرى على العلامات الثلاثة واجمعها بالتقارب والتباعد وأدر قوسًا من مدار السرطان إلى مدار الجدي أو من السرطان إلى قوس الدائرة

<فـ> كُمِل <الوضع>

<**شكل**> شكل المساترة النهارية لعرض لو

D:73v P:34r

البـــاب ند في معرفة وضع المساترة اللّيلية

وذلك أن تدير دائرة وتربّعها وافعل كما فعلت في النهارية وإنّما تأخذ سعة المشارق والمغارب من هذا الجدول المكتوب في هذه الورقة لكلّ مقنطرة وتفعل كما فعلت بسعة مشرق البروج وسعة مغاربها فإذا كُمِلت علامات سعة مشارق البعد ومغاربها <فضع المصطرة على قطب التسطيح وعلى عدد غاية كلّ مدار من قسمة الدائرة مبتدئاً من نقطة الجنوب وعلّم على تقاطع جنب المصطرة لخطّ الزوال> فاجمعها[9] مداراتا كما جمعت مدارات البروج في النهارية إلى أن تُتكمّل قسي مدارات هذه المساترة إلى مائة وثمانين فاكتب عليها أعدادها فإذا كُمِلت مدارات سعة المشارق والمغارب فعلّم على خطّ العلاقة بقدر الارتفاع الأعلى والأدنى فاجمعهما دوائر كاملة فقد كُمِلت المدارات

فإن أردت <فضل> الدائر فاجمع قطبي التسطيح وقطب معدّل النهار وأدره قوسًا إلى طرفي الدائرة الكبرى وهو قوس أوّل <فضل> الدائر فخطّ خطّ مشرق هذا القوس ثم خذ من جدول المقنطرات المتقدّم بقدر سمت عشرة عشرة لرأس الاعتدال وخذ ما بحياله من عدد الارتفاع وضع رجل البركار في المركز ورجله الأخرى على مقنطرة الارتفاع وانقل رجله على قوس مدار الاعتدال وعلّم

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[8] <لفضل> الدائر] للدائر **P**; المدار **D** [9] فاجمعهما **P,D**

على أفق طلوع الجزء أو غروبه وعلّم برجله الأخرى على مدار ذلك الجزء فإذا عملت على المدارات الثلاثة فاجمع تلك العلامات من الأفق إلى دائرة الجدي وهي الكبرى واعلم أنّ فتحة قوس الأفق هي فتحة قسي الساعات من غير أن تغيّر فتحة البركار

<شكل> شكل الساعات المستوية بانفرادها — صفيحة الساعات لعرض لوَ

البـــاب نجَ في معرفة وضع المساترة النهارية D:73r P:28v

أدر دائرة وربّعها ثم خذ من هذا الجدول المستخرج من جداول الدائر[3] المتقدّمة بقدر سعة مشرق الدرجة وعدّ بمثله في الدائرة الكبرى وعلّم علامة من جهة المشرق وعلامة من جهة المغرب وضع المصطرة على عدد المقنطرة من قسمة الدائرة مبتدئاً من العلاقة وعلى نقطة ابتداء عدد قوس الربع وعلّم على <تقاطع> جنب المصطرة لخطّ العلاقة <ولا تزال تفعل ذلك> إلى أن تكمل <علامات> المقنطرات ثم عدّ في <علامات> المقنطرات بقدر غاية الدرجة مبتدئاً من نقطة الجنوب <وعلّم> وضع رجل البركار على خطّ الوتد وتتباعد وتتقارب برجله حتى تجمع موضع الغاية وعلامتي سعة المشرق والمغرب قوسًا إلى طرفي[4] الدائرة يمينًا ويسارًا فهو مدار ذلك البرج فإذا تكمّلت البروج فاكتب أسماءها[5]

ثم علّم على نقطة سمت الرأس وضع رجله على خطّ العلاقة ولا تزال تتقدّم برجله وتتأخّر حتى تجمع بين[6] نقطتي قطب التسطيح ونقطة سمت الرأس فأدر برجله قوسًا من مدار السرطان إلى قطب التسطيح من جهة اليمين واليسار على قوس الدائرة

فإن أردت المقنطرات فضع رجله في المركز والأخرى على علامة كلّ مقنطرة وأدر برجله[7] الأخرى قوسًا من مدار الجدي إلى مدار السرطان وقد توضع على العضادة

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[3] الدائرة D [4] طرف P,D [5] أسماهم P,D [6] من P [7] وادير برجله D; واد برجله P

وهذا الشكل يوضع في ظهر كلّ ربع مقدّم وضعه إذا لم يعلم السمت من قوس الربع

<شكل> شكل الربع السمتي لعرض لو

<ملاحظة> هذا الربع ينبغي أن يكون في ظهر كلّ ربع من أرباع المقنطرات الموضوعة المتقدّم ذكرها إذا لم يعلم السمت من قوس الربع

البـــاب نا في معرفة وضع الساعات الزمانية والمستوية

D:72r

فإنّ الصفائح المتقدّم وضعها ليس فيها[8] قسي الساعات فكبر بنا أن نصوّرها[9] لنكمل[10] وضع الآلات المتقدّمة إذا أردت ذلك أدر دائرة وربّعها وأدر المدارات الثالث كما تقدّم واعلم الارتفاع لتلك الساعة الزمانية أو مستوية لكلّ مدار وضع رجل البركار على نقطة طلوع الحمل <ونقطة طلوع الجدي ونقطة طلوع السرطان> ورجله الأخرى على ذلك الارتفاع وانقله بفتحته حتى تضع رجله على موضع أفق طلوع الجزء وغروبه فإذا علّمت على المدارات الثلاث فاجمع تلك العلامات قوسًا فهي[11] قسي الساعات الزمانية والمستوية وفتحتها هي فتحة الأفق

<شكل> صفيحة الساعات لعرض لو

الأولة، الثانية ... الثانية عشر — الساعات الزمانية بالأحمر والساعات المستوية بالأسود

البـــاب نب في معرفة وضع الساعات المستوية بوجه آخر

D:72v
P:28r

أدر دائرة وربّعها وأدر دائرة الاعتدال والسرطان واعلم الارتفاع لدائر خمسة عشر من جداول الدائر[1] كما تقدّم لكلّ مدار منها[2] وضع رجل البركار على نقطة طلوع الحمل ونقطة طلوع الجدي ونقطة طلوع السرطان ورجله الأخرى على مقنطرة الارتفاع الموافق لأجزاء تلك الساعة وانقله بفتحته حتى تضع رجله

[8] **MS** فيهم [9] **MS** تصورها [10] **MS** لتكملت [11] **MS** فهما [1] **P,D** جدول الدائر [2] **P,D** منهما

واعلم أن هذه الأرباع الثمانية المشكلة لا يشبه شكلها لغيره فتركنا الباقي بسبب ذلك ولا تختلف أشكالها إلّا إذا كانت صفيحة كاملة المدارات ولا يمكن تشكيل ربعها

<شكل> شكل الربع الباطي لعرض لوَ

اعلم أن سائر الأرباع المتقدّم وضعها ترسم بغير فضلة في الربع أعني لم يكن فيه زيادة ولم أطلع على من ذكر طريق العمل به وقد ذكر بعض الناس أنّه يعلم من جهة النظير وهذا خطأ كبير[5] وليس له صحّة

وإنّما الطريق في اخراج الدائر إذا خرج الخيط عن الربع أن تجعل مريًا[6] ثانيًا في الخيط على موضع تَقاطُع الخيط للأفق ثم تنقل الخيط إلى خطّ الزوال منتظِّرًا إلى ما وقع عليه الموريّن من عدد المقنطرات مبتدئاً من مدار الاعتدال فخذ بمثلها من الجهة الأخرى وانقل الخيط حتى تضع كلّ من الموريّن على الأفق وانظر ما يتحرّك الخيط عن موضعه من قوس الربع فهو الدائر لذلك الارتفاع ويعمل ذلك أيضًا من ربع المقنطرات

الباب نَ في معرفة <وضع> الربع السمتي D:71v

وذلك أنّ الأرباع المتقدّم وضعها ليس رسم قسي السموت بسبب إطلاقها فاستخرجنا بها سمت من الجداول ووضعنا به هذا الربع ومعرفة وضعه فأدر ربع دائرة وربّعها بخطّين واعلم الدائر من الجدول لكلّ عشرة من السمت وعلّم بعدده على قوس الربع وخذ فتحة بالبركار بقدر بعد سمت الرأس وضع رجل البركار على خطّ <آخر> الربع والرجل الأخرى على نقطة سمت الرأس ولا تزال تتقارب وتتباعد برجله حتى تجمع قطبي التسطيح ونقطة سمت الرأس فاثبت رجله على خطّ مشرق الدائرة[7] السمتية وأدر برجله التي على نقطة سمت الرأس قوسًا إلى علامة قوس الربع فهو قوس السمت وكمّلها واكتب عددها

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[5] MS كبيرًا [6] MS مري [7] MS الدائر

الجدول المتقدّم لوضع المقنطرات ثم ضع[3] رجل البركار على خطّ آخر الربع واجمع الثلاث علامات الداخلة دائرة الاعتدال والخارجة عنه وصل بعضها ببعض واكتب عليها أعدادها وأمّا السمت فتركه أصلح وأحسن ما يعلم السمت من الربع السمتي وسيأتي ذكره

<شكل> شكل الربع السحلفي[4] لعرض لو

البـــاب مح في معرفة وضع ربع الأصطرلاب الثوري D:70v

وذلك أن تدير ربع دائرة وتربّعها بخطّين وتقسم ذلك القوس ص وهو دائرة أحد المنقلبين ثم تدير مدار المنقلب الآخر ومدار الاعتدال كما تقدّم ثم علّم كلّ مدار من هذه الثلاثة بقدر فضل الدائر المكتوب بحيال كلّ مقنطرة من الجدول المتقدّم لوضع المقنطرات ثم ضع رجل البركار على خطّ المركز المارّ بآخر الربع واجمع العلامات الثلاثة الداخلة في دائرة الاعتدال والخارجة عنه وصل بعضها ببعض واكتب عليها أعدادها وأمّا السموت فتركها أصلح وأحسن ما يعلم السمت من الربع السمتي وسيأتي ذكره

<شكل> شكل الربع الثوري لعرض لو

البـــاب مط في معرفة وضع ربع الأصطرلاب الباطي D:71r

وهو أن تدير ربع دائرة وتربّعها بخطّين ثم تقسم ذلك القوس ص وهو مدار أحد المنقلبين ثم تدير مدار أحد المنقلبين الآخر ومدار الاعتدال كما تقدّم ثم علّم على كلّ مدار من هذه الثلاثة بقدر فضل الدائر المكتوب بحيال كلّ مقنطرة من الجدول المتقدّم ذكره لوضع المقنطرات ثم ضع رجل البركار على خطّ آخر الربع واجمع تلك العلامات الثلاث من داخلة مدار الاعتدال وخارجًا عنه <فصِل> (؟) بعضها ببعض واكتب <عليها> أعدادها وأمّا السمت فتركه أصلح وأحسن ما يُعلَم السمت من الربع السمتي وهو بعد هذا

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[3] اضع **P** [4] *Sic* **P**; الزحلفي **D**

وتتقدّم أو تتأخّر حتى تجمع تلك العلامات فهي[9] المقنطرات المقوّسة إلى جهة خطّ آخر الربع

فإن أردت المقنطرات المقوّسة إلى جهة أوّل الربع فعلّم بقدر فضل الدائر أيضًا المكتوب في الجدول المذكور على مدار النظير فإذا كُمِلت علامات الثلاث مدارات فاجمعها قوسًا حتى تتكمّل جميع المقنطرات فاكتب عليها أعدادها وأمّا السمت فتركه أصلح وأحسن ما يُعلَم السمت[10] من الربع السمتي وسيأتي ذكره

<شكل> شكل الربع الآسي وهو ربع المطبّل لعرض لو

البـــاب مو في معرفة وضع ربع الأصطرلاب الزورقي

D:69v **P**:27r

وهو أن تدير ربع دائرة وتربّعها بخطّين ثم تقسم قوس الربع ص وهو دائرة أحد المنقلبين ثم تدير مدار المنقلب الآخر كما تقدّم ومدار الاعتدال ثم علّم على كلّ مدار من هذه الثلاثة بقدر فضل الدائر المكتوب بحيال كلّ مقنطرة من الجدول المتقدّم لوضع المقنطرات ثم ضع[1] رجل البركار على خطّ آخر الربع وتتقدّم أو تتأخّر حتى تجمع تلك العلامات ويكون اتّصالها بالأفق فإذا تكمّلت المقنطرات المذكورة من داخل الأفق وخارجًا عنه فصل الداخلة بعضها ببعض واكتب عليها أعدادها بين قسي المقنطرات حيث شئت إلى أن تكمل جميع المقنطرات وأمّا السمت فكما تقدّم وأحسنه أن يكون من ربع دائرة السمتية الذي يأتي ذكره

<شكل> شكل الربع الزورقي لعرض لو

البـــاب مز في معرفة وضع ربع الأصطرلاب السحلفي[2]

D:70r **P**:27v

وهو أن تدير ربع دائرة وتربّعها بخطّين ثم تقسم ذلك القوس ص وهو دائرة أحد المنقلبين ثم تدير مدار المنقلب الآخر ومدار الاعتدال كما تقدّم ثم علّم على كلّ مدار من هذه الثلاثة بقدر فضل الدائر المكتوب بحيال كلّ مقنطرة من

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[9] فهم **P,D** [10] السمت marg. **D** [1] اضع **P** [2] *Sic* **P,D**. Cf. Ch. 21.

<شكل> <شكل ربع الأصطرلاب الآفاقي>

D:68v
P:33r

البـــاب مد في معرفة وضع ربع الأصطرلاب المتكافئ

وأن تدير ربع دائرة وتربّعها[1] بخطّين ثم تدير مدار الاعتدال والسرطان ثم ضع[2] المصطرة على تفاضل[3] الدائر لكلّ مقنطرة من الجدول المحسوب لوضع المقنطرات لثلاث مدارات وعلّم على كلّ مدار منها[4] واجمع تلك العلامات برجل البركار فإذا تكمّل مدار الجدي وهو الأكبر فاجمع علامات الاعتدال والسرطان فإذا كُمِلت مقنطرات الاعتدال فاستخرج فضل الدائر للكوكبين المذكورين في الجدول واجمع تلك العلامات الثلاث قسيًّا[5] فقد كُمِلت المقنطرات الأولى[6] المتّصلة بقوس الربع فإن أردت المقنطرات الثانية المتّصلة بالأفق فضع رجل البركار على الزوال من خارج الربع وعلى مقنطرة عرض البلد الموضوع له ذلك وعلى تقاطع دائرة الاعتدال لخطّ المشرق وأدر قوسًا منه إلى خطّ الزوال فهو الأفق الثاني ثم انقل رجله إلى المقنطرة التي دون الأفق وعلى مقاطعة تلك المقنطرة لمدار السرطان وأدره قوسًا إلى خطّ الزوال تفعل ذلك[7] حتى تتكمّل المقنطرات وأمّا السموت فأحسنها أن تُعلَم من الربع المسمّت

<شكل> شكل ربع الأصطرلاب المتكافئ لعرض لو

D:69r
P:33v

البـــاب مه في معرفة وضع ربع الأصطرلاب الآسي وهو ربع الأصطرلاب المطبّل

وهو أن تدير ربع دائرة وتربّعها بخطّين ثم تقسم ذلك القوس ص وهو دائرة أحد المنقلبين ثم تدير مدار أحد المنقلبين الآخر ومدار الاعتدال كما تقدّم ثم علّم كلّ مدار من هذه الثلاثة بقدر فضل الدائر المكتوب بحيال كلّ مقنطرة من الجدول المتقدّم لوضع المقنطرات ثم ضع[8] رجل البركار على خطّ آخر الربع

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[1] ربعها D [2] اضع P [3] تفاطل P [4] منهما P,D [5] قسي P,D [6] الأول D [7] ذلك om. D
[8] اضع P

السمتية وسوف يأتي ذكرها بعد الأرباع فإنّ كلّ ربع ليس يكون مسمّتًا يُعلَم منها وأحسن ما يُعلَم السمت من ربع الدائرة السمتية فإنّه يظلم[8]

<شكل> شكل الربع اللّولبي لعرض لو

البـــاب مجـ في معرفة وضع ربع الأصطرلاب الآفاقي D:68r P:29v

وهو أن تدير ربع دارة وتربّعها[9] بخطّين ثم تدير مدار الاعتدال والسرطان ثم اقسم ما بين المركز ودائرة الاعتدال يط لط وخذ من تلك القسمة بقدر نصف قطر كلّ مقنطرة ⌈ من جدول أنصاف[10] الأقطار ⌉[11] وضع رجل البركار في المركز والأخرى حيث وقعت على خطّ الزوال ⌈ وعلّم علامات المقنطرات ⌉[12] ثم انقل البركار حتى تضعه على خطّ الزوال ورجله الأخرى على علامة المقنطرة وعلى عددها من قوس الربع واجمعها[13] قوسًا بالتقارب والتباعد حتى تتكمّل جميع المقنطرات

وأمّا السمت فضع رجل البركار في المركز ورجله الأخرى على كلّ علامة من علامات المقنطرات واثبت رجله التي في المركز وانقل رجله الأخرى على خطّ المشرق فإذا كملت العلامات التي على خطّ نصف النهار إلى خطّ المشرق فضع رجل البركار على خطّ المشرق من خارج الربع وعلى كلّ علامة فيه وعلى مقنطرة ص وأدره قوسًا إلى مقنطرة ص فإذا كملت العلامات الداخلة دائرة الاعتدال فضع رجله على خطّ المشرق من داخل الربع وعلى كلّ[14] علامة من الباقيين وعلى نقطة ص وأدر قوسًا فهي قسي السموت ثم ضع رجله في المركز ورجله الأخرى على كلّ علامة من خطّ الزوال وأدر برجله قوسًا من خطّ الزوال إلى خطّ المشرق فقد كُمِل وضعه

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[8] Cf. Chs 8 + 13 [9] وتربعها om. **D** [10] أنطاف **D**: see the second note below [11] ⌈…⌉ : من الجدول (!) أنصاف الأقطار marg. **P**; وعلّم علامات المقنطرات **D** (cf. next note) [12] ⌈…⌉ : وعلم علامات المقنطرات marg. **P**; من جدول أنطاف (!) الأقطار **D** – the two marginal corrections in **P** indicated in this note and the previous one are in fact interchangeable, since they occur in relation to the same line of text. But the meaning of the text forces us to insert them the way we did. This means that both marginal corrections in **P** were confused by the copyist of **D** who inserted them incorrectly in his text. See further p. 35 of the introduction. [13] واجمعهما **P**,**D**
[14] كل om. **P**

المستقيم وعلّم علامات المدارات عليه ثم انقل[12] بفتحة <بقدر بعد> خمسة خمسة من قوس الربع <عن آخره> وضع رجله في موضع تقاطع الخطّ لقوس الربع <وعلّمه عليه> واضرب برجله من جهة اليمين واليسار إلّا[13] أن يخرج عن الربع ثم ضع[14] رجله على الخطّ المستقيم ورجله الأخرى على كلّ من العلامتين وأدر به قوسًا يقاطع طرفي هذا القوس فهي[15] مدارات الزرقالة[16] المخالفة لمدارات الشكّازية وموضع <آخر> هذا الخطّ هو موضع قطب تلك البروج

<شكل> شكل ربع الزرقالة

D:67v **P**:29r

البـــاب مب في معرفة وضع ربع الأصطرلاب اللّولبي

وهو أن تدير <ربع> دائرة وتربّعها بخطّين ثم اقسم نصف القطر ل وخذ من تلك القسمة بقدر نصف قطر الاعتدال وهو يط لط دقيقة وضع رجله في المركز وأدر قوسًا فهو مدار الاعتدال ثم خذ فتحة بقدر نصف قطر أحد المنقلبين يب ند دقيقة وافعل كذلك فهو مدار أحد المنقلبين منسوبًا إلى جهة العرض ثم خذ فتحة بقدر[1] تفاضل[2] الدائر للأفق المكتوب في الجدول المتقدّم الذي وضعت به المقنطرات وضع رجله على خطّ الزوال موضع تَقاطُعه[3] للقوس[4] الأكبر وعلّم برجله الأخرى في قوس الدائرة الكبرى وضع المصطرة على فضل الدائر مبتدئاً من آخر الربع وعلّم على مدار الاعتدال وعلى مدار أحد المنقلبين فقد حصل ثلاث علامات فاجمعها[5] قوسًا فهو قوس تلك المقنطرة

فإن أردت السمت فخذ فتحة بقدر ما بحيال جدول السمت من قسمة بعد مركز دائرة أوّل السموت وضع رجله في قطب التسطيح والأخرى حيث وقعت على خطّ الوتد ومدّ خطًّا مستقيمًا فهو خطّ مشرق دائرة أوّل السموت فاجمعها[6] على نقطة سمت الرأس كما تقدّم وإن شئت تركه[7] فيُعلم من ربع الدائرة

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[12] انقله **P,D** [13] إلّا] إلى **D** [14] اضع **P** [15] فهما **P,D** [16] The ر is written underneath the ة in **P**. [1] بقلر **P** [2] تفاطل **P,D** [3] تقاطه **P** [4] لقوس **P** [5] فاجمعهما **P,D** [6] فاجمعهما **P,D**
[7] تركه **D**

به من الجهة الأخرى كذلك على القطب وأدر برجله فهو المرّ فافعل ذلك حتى يُتكمّل الربع ومدّ خطّ الطول من المركز إلى الميل الأعظم واكتب عدد قسي الممرّات على خطّ التربيع ثمّ ضع رجل البركار في المركز والأخرى على مطالع الحمل بالفلك وانقلها إلى خطّ الطول وعلّم علامة وكذلك مطالع الثور والجوزاء واكتب على خطّ الطول أسماء البروج الاثنا عشر مستقيمًا وراجعًا

<شكل> شكل ربع السكّازية

جدول أنصاف الأقطار[4]

مقنطرات	فه	ف	عه	ع	سه	س	نه	ن	مه
أنصاف الأقطار	يح ﮴	يو ل	يه ز *	يجمو	يب لب	يا كا	ي يه	ط ي	ح ط
مقنطرات	م	له	ل	كه	ك	يه	ي	ه	
أنصاف الأقطار	ز يا	و يب	ه يو	د كا	جكح	ب لد	ا مج	﮴ نا	

* يه ن D

البـــاب ما في معرفة وضع[5] ربع الزرقالة
D:67r
P:5v

وهي ربع الشكّازية مركّبة فوق ربع شكّازية أخرى لكنّها مخالفة لقسي الأخرى وذلك[6] أن تدير ربع[7] دائرة وربّعها وتقسمها ص قسمًا ثم افعل ما فعلته أوّلًا في ربع الشكّازية وأدر المدارات والممرّات كما تُقدّم ثم ضع[8] المصطرة على المركز وعلى الميل الأعظم مبتدأً[9] من آخر الربع ثم مدّه خطًّا مستقيمًا بغير نهاية وهميًا[10] ثم ضع[11] رجل البركار في المركز ورجله الأخرى على خطّ أجزاء الربع بقدر قسمة المدارات واثبت رجله إلى المركز وانقل الأخرى إلى الخطّ

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[4] جدول مواقع **P**. The arguments are labelled مقنطرات in both **D** and **P** and the entries are labelled نصف القطر in **D** and مواقع in **P**. The arguments are correctly labelled 85–5 in **P**, but in **D** they are in the reverse order 5–85, with entries moreover shifted one line to the top. In **D** the entry vis-à-vis argument 85 is erroneously labelled نصف القطر, which in fact corresponds to the entry for argument 90. This table also belongs to Ch. 41. [5] وضع marg. **P** [6] ذالك **P** [7] ربع om. **D** [8] اضع **P** [9] مبتد **P**,**D** [10] بغير نهاية وهميًا marg. **P**; وهميًا om. **D** [11] اضع **P**

وهذا الجدول يغني عن وضع المصطرة لهذه الآلة والزرقالة[17] والمساترة والربع المستّر والصفيحة[18] الشجّارية وغير ذلك من[19] أرباع هذه الآلات المذكورة على أنّ نصف القطر لَ[20]

<شكل> شكل صفيحة الشكّازية وهي آلة آفاقية[21]

مقنطرات	و	يب	يح	كد	ل	لو	مب	مح
نصف القطر	الج	جز	د مج	و كد	ح ا	ط مه	يا كط	يجك
مقنطرات	ند	س	سو	عب	عح	فد	ص	
نصف القطر	يه يو	يزك	يط ل	كا مد	كد يز	كز ذ	ل ذ	

هذا الجدول لقسي المرّات من الشكّازية والزرقالة ودوائر الارتفاع في المساترة وأنصاف الأقطار لبلد لا عرض له ونصف القطر من الربع[22] المستّر يجب أن تكون نصف قطر الصفيحة لَ جزءًا[23] متساويًا

D:67r
P:5v

البـــاب مَ في معرفة وضع ربع الشكّازية

أدر دائرة وربّعها واقسمها صَ قسمًا ثم خذ بقدر الدائر خمسة أو غير ذلك من الجداول لبلد لا عرض له لرأس الاعتدالين فوجدنا الارتفاع موافقًا للدائر فتركنا جدوله بسبب ذلك ثم استخرجنا جدولًا من باب أنصاف الأقطار وهو هذا المذكور المجدول هنا لنستعين به في ربع الشكّازية وربع[1] الزرقالة ثم قسمنا أحد خطّي التربيع بقدر نصف قطر الاعتدالين وهو يط لط دقيقة وأخذنا من تلك القسمة بقدر ما يحصّ كلّ مقنطرة ممّا بحيالها وتضع رجل البركار[2] على ذلك الخطّ وعلى كلّ[3] قسم من الربع وأدر برجله الأخرى قوسًا فهو المدار وافعل

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[17] لهذه الآلة والزرقالة om. **D** [18] والصفحة **P** [19] وغير ذلك من] وكذالك (؟) **P** [20] لَ om. **D**
[21] Caption om. **D** [22] المربع **D** [23] جزوا **P,D** [1] ربع over the line **P** [2] Here the symbol ٢ is inserted in **P**, probably referring to the marginal *addendum* مركز والأخرى, but this does not appear to fit in the text. [3] كل] وكل **P**

البـــاب لطَ في معرفة وضع الشكّازية وهو أن ندير دائرة ونربّعها[1] ونستخرج لها جدولًا من جداول الدائر لبلد لا عرض له لرأس الاعتدال فوجدنا الارتفاع موافقًا للدائر فتركنا جدوله بسبب ذلك[2] فوضعنا المصطرة على قطب التسطيح وعلى عدد المقنطرة ونعلّم على[3] تقاطعها[4] لخطّ العلاقة ثم وضعنا رجل البركار على خطّ نقطتي الشمال والجنوب وأدرنا برجله الأخرى نصف[5] دائرة على قسمة[6] الدائرة العظمى وهي مدار الاعتدال ولا نزال نفعل ذلك[7] إلى أن تُتكمّل المقنطرات D:66v P:5r

وأمّا السموت فضع[8] رجله على خطّ وسط الدائرة المقاطع[9] لخطّ نقطتي الشمال والجنوب وأدر برجله قوسًا من جهتي نقطتي الشمال والجنوب حتى تُتكمّل قسي السموت وهذه صفيحة[10] بلد لا عرض له كاملة من الجنس

وأمّا خطّ الطول فمدّ خطًّا يمرّ بالمركز بقدر الميل الأعظم ثم مدّ خطّ العرض[11] بقدر تمام الميل الأعظم يمرّ بالمركز ثم اكتب على خطّ أحد التربيع المارّ بأوّل عدد الدائرة قسمة الفلك وهو شس وخذ من تلك القسمة بقدر مطالع البرج بالفلك مبتدئاً بالجدي وعلّم علامة ثم ضع[12] رجله[13] على خطّ الطول والأخرى على تلك العلامة وعلى تمام الميل الأعظم من الجهتين وهي[14] قطبي فلك البروج وأدر برجله قوسًا متّصلًا بطرفي الدائرة فهي[15] قسي البروج

وإن شئت فاستخرج نصف القطرين على مقنطرة وذلك أن تأخذ ظلّ نصف عدد[16] المقنطرة منكوس وزد عليه ثلثيه فما حصل انقص منه لكلّ درجة دقيقة فما بقي زد عليه نصفه فما اجتمع زد عليه لكلّ درجة دقيقة فهو المطلوب

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[1] وتربعها D [2] ذالك P [3] على written over a deleted word in P [4] تقاتعها] نتقاطعه ها P
[5] نصف over the line P [6] قسمة] (؟) فتحتها P; (!) صحته D; the reading قسمة is confirmed by Ch. 9. [7] ذالك P [8] اضع P [9] المفاطع P [10] صفحة P (written over an erased word)
[11] خط العرض] خطا لعرض D ('corrected' with a lone ا written over the final one) [12] اضع P
[13] رجله om. D [14] هما P,D [15] فهما P,D [16] ظل نصف عدد] ... (؟) على هذه D

ببعدها وجهته ومطالع كلّ منها[4] أو جزء ممرّها

<شكل> <شبكة الأصطرلاب الهلالي>

(أسماء البروج) — <التسطيح الشمالى:> عين الثور، الشعرى العبور، قلب الاسد، السماك الأعزل، رأس الحوّاء، الطائر، ذنب قيطس — <التسطيح الجنوبى:> رجل السرطان، نيّر الهنعة، الصرفة

البـــاب لحَ في معرفة وضع الأصطرلاب المصطري D:66r

وهو الشمالي الأوّل وهو أحسن الأشكال وأقربها إلى الهيئة وأحسنها أبوابًا في الرسائل بأنّ (!)[5] بعض هذه الأشكال في رسالته عسرًا و <لا> يتبيّن على من لا له فهم في الكيفية في تركيب أشكالها ولأجل هذا بدأنا به في أوّل الوضع واختتمنا به في آخر الوضع وهو تمام ثلاثون أصطرلابًا (!!) فإذا أردت وضعه فافعل ما فعلت بالشمالي ولا يحتاج أن نعيد وضعه فافهم تصب

واعلم أنّ كلّ أصطرلاب منها المتقدّم وضعها إلّا الأكري وذات الحلق إذا ركبت عليه هذه المصطرة سمّي مصطري أو خيط يغني عن المصطرة وينبغي أن تكون الكواكب مرسومة في العضادة وهي المحرّكة على وجه الصفيحة ولو لا ذكره البيروني في كتابه ما صوّرتُه هنا وإنّما كثير[6] من الصفائح ليس لها[7] شبكة إمّا أن تكون مركّب عليها عضادة أو خيط فإن كان خيط ينبغي أن تُرسم كواكبه في الصفيحة كالمُجمّد والعضادة تُرسم عليها الكواكب

<شكل> صفيحة الشمالي على صفيحة المصطري

وأمّا وضع العضادة وهو أن تأخذ فتحة بقدر نصف قطر الصفيحة وتضع رجل البركار في قطب العضادة وتعلّم على موضع[8] رجله الأخرى من الناحيتين ثم تأخذ فتحة بقدر غاية ارتفاع كلّ برج وتضع رجله في مركز العضادة والأخرى حيث وقعت على حرف العضادة فهو موضع البرج وأمّا الكواكب فببعدها ومطالعها كما تقدّم

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[4] منهما **MS** [5] Should be مع أنّ [6] كبر **MS** [7] لهما **MS** [8] موضع written underneath رجله **MS**

البـــاب لزَ في معرفة وضع الأصطرلاب الهلالي D:65r P:21v

وهو العاشر ممّا استنبطناه ولو لا يطول الشرح لاستنبطنا أكثر من ذلك فإنّ أشكالها[1] إذا رسمت مع شكل آخر موافق لجنس المقنطرات تغيّرت أشكال الصفائح فوجدت ذلك لا يتناهي ووجدت أحسن أشكالها الشمالي أو الجنوبي المذكور كلّ منهما في أوّل الأبواب فلأجل هذا اختصرنا على عشرة منها[2] مع ما وضعه البيروني وهو سبعة عشر صفيحة وثلاثة مشهورة وهي[3] الأكري وذات الحلق والمصطري فجملة ذلك ثلاثون

وإذا أردت وضع هذه الصفيحة فهي وضع الجنوبي المتكافئ وهو باب لجَ والمقنطرات الداخلة في وسطه فهي مقنطرات المتداخل المتخالف وهو الباب لهَ لكنّها كاملة من جهة المشرق والمغرب فاكتب عليها أعدادها والسمت كما تقدّم أو من الحجرة

<شكل> <صفيحة الأصطرلاب الهلالي>

D:65v **وأمّا الشبكة** وهو أن تأخذ فتحة بالبركار بقدر أكبر دوائر الصفيحة وتضع رجله <في المركز ورجله الأخرى> في موضع آخر وتدير برجله الأخرى دائرة ثم تربّع ثم خذ فتحة أيضًا بقدر ما بين مدار السرطان والجدي على خطّين من خطوط الصفيحة أعني مخالفًا في الجهة وانقله بفتحته حتى تضعه في خطّ تربيع الشبكة مع الدائرة الكبرى والرجل الأخرى حيث وقعت على خطّ التربيع فأدر نصف دائرة وهي نصف منطقة البروج ثم انقله بفتحته أيضًا إلى خطّ التربيع الآخر وأدر برجله نصف دائرة فهي النصف الآخر من المنطقة وأحسن ما يوضع على هذه الصفة وقد يستغني بنصف الدائرة الكبرى عن كاملها واكتب أسماء البروج في كلّ منهما شبه في الأولى وشبه في الثانية وأمّا الكواكب فكما تقدّم

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[1] أشكالهما **P,D** [2] منهما **P,D** [3] وهما **P,D**

D:64r
P:36v

البـــاب لوَ في معرفة وضع الأصطرلاب المتداخل الموافق

وهو منسوب إلى وضع الصفيحة كون إنّ المقنطرات داخلة في الصفيحة متّفقة لبعضها البعض[4] وذلك أن تدير دائرة وتدير الثلاث دوائر كما تقدّم ثم خذ من الجدول بقدر ما بحيال كلّ مقنطرة من فضل الدائر من جدول الشمال والجنوب وخذ بقدره من كلّ مدار من الثلاثة <وعلّم على كلّ مدار> واجمع العلامات الثلاث <قسيًا> فهي[5] قسي المقنطرات فصل بعضها[6] ببعض وأمّا السموت فكما ذكرنا من الحجرة

<**شكل**> صفيحة المتداخل الموافق

استنبط هذا الشكل مصنّف هذا الكتاب

D:64v
P:21r

وأمّا وضع الشبكة وهو أن تدير دائرة قدر أكبر دوائر الصفيحة ثم أدر دائرة أصغر منها تحوز أسماء البروج وهي منطقة البروج ثم تضع المصطرة على مركز الشبكة وعلى مطالع كلّ برج بالفلك من أقسام الدائرة الكبرى ومدّ خطًّا بين تلك الدائرتين فقد حُرِّرَت[7] البروج فاكتب أسماءها وأسماء نظائرها[8] في موضع واحد

وأمّا الكواكب فضع رجل البركار في مركز الصفيحة ورجله الأخرى على بعده من جهته وانقله بفتحته حتى تضع <رجله> في[9] مركز الشبكة ورجله الأخرى حيث وقعت على خطّ درجة جزء ممرّه فهو موضع الكوكب فاكتب عليه[10] اسمه وينبغي أن تكون في هذه الشبكة سائر الكواكب من جهة الشمال والجنوب وقد تركنا فسحها (؟؟؟) على اليمين (؟)[11]

<**شكل**> شبكة المتداخل الموافق

(أسماء البروج: مرّتين) — <التسطيح الشمالى:> عين الثور، قلب الاسد، وسط الغفر، الفكّة، رأس الحوّاء، الطائر، الردف، ذنب قيطس — <التسطيح الجنوبى:> سهيل اليمن

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4 لبعضها البعض] لبعضها لبعض P,D   5 فهما P,D   6 بعضهم P,D   7 حرت P,D
8 أسمائهم وأسماء نظائرهم P,D   9 من D   10 على P   11 اليمن D

D:63r P:19v البـــاب لهَ في معرفة وضع الأصطرلاب المتداخل المتخالف

وهو منسوب إلى وضع الصفيحة كون أنّ المقنطرات داخلة في الصفيحة مخالفة بعضها لبعض وذلك أن تدير دائرة وتربّعها وتدير المدارات

الثلاث كما تقدّم ثم خذ ما بحيال كلّ مقنطرة من الجدول وعلّم بمثله في كلّ مدار من الثلاثة واجمع تلك العلامات فهي[1] قسي المقنطرات ثم افعل ذلك بين الأفقين على خطّ التربيع واكتب عليها أعدادها وأمّا السموت فكما تقدّم وأحسنه من الدائرة السمتية أو من الحجرة

<شكل> صفيحة المتداخل المتخالف لعرض لوَ

استنبط هذا الشكل مصنّف هذا الكتاب

D:63v P:36r **وأمّا الشبكة** وهو أن تدير دائرة وتربّعها ثم اعلم موضع قطب فلك البروج وتضع رجل البركار فيه وأدر دائرة كاملة ثم دائرة أصغر منها لتحوز أسماء البروج وهي المنطقة ثم اكتب أسماء البروج ونظائرها كلّ برج مع نظيره ثم ضع المصطرة على المركز وعلى مطالع كلّ برج بالفلك وخذ خطًّا بين تلك الدائرتين إلى أن تُكمل البروج وأمّا الكواكب فببعدها ومطالعها كما تقدّم وينبغي أن تكون الشمالية مركّب[2] على مطالعها من البروج المكتوبة بالأسود والجنوبية بالعكس

<شكل> شبكة المتداخل المتخالف

(أسماء البروج: مرّتين) — أصل ذنب قيطس[3] ، عين الثور، رجل الجوزاء، واقع، الغميصا، قلب الاسد، ردف، جناح الغراب، الاعزل، الرامح، الفكّة، رأس الحوّاء، طائر، ركبة الدجاجة، الصرفة، ذنب قيطس

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[1] فهما P,D   [2] تركب P; بركب D   [3] ذنب قيطش D

D:62r
P:4v

البـــاب لدَ في معرفة وضع الأصطرلاب المعقرب

وهو منسوب إلى وضع شبكته وهو أن تدير دائرة وتربّعها ثم تدير دوائر[10] المنقلبين ودائرة الاعتدال كما تقدّم ثم تأخذ من الجدول ما بحيال كلّ مقنطرة لكلّ مدارات الثلاث وتعلّم على كلّ مدار بقدر ذلك واجمع علامات فهي[11] قسي المقنطرات وكلّ جهة مخالفة للأخرى واكتب عليها أعدادها وأمّا السموت فتركها أصلح وأحسن ما يعلم السمت من الدائرة السمتية المتقدّم وضعها أو من الحجرة من أبواب الرسالت الآتية

<شكل> صفيحة المعقرب لعرض لوَ

استنبطه مصنّف هذا الكتاب[12]

D:62v
P:19r

وأمّا الشبكة وهو أن تدير دائرة قدر أكبر الدوائر في الصفيحة وتربّعها ثم خذ بقدر ما من بين مدار الجدي ومدار السرطان وهي فتحة فلك البروج[13] وضع رجل البركار على الدائرة الكبرى للشبكة والرجل الأخرى حيث وقعت على خطّ التربيع فاثبتها وأدر برجله التي على الدائرة نصف دائرة من أحد <طرفي> خطّ التربيع الآخر إلى الجهة الأخرى وافعل أيضًا نصف دائرة مثلها <إلى الجهة المقابلة> وأدر قوسًا <دونهما> يحوز أسماء البروج وإنّما الكواكب فببعدها ومطالعها كما تقدّم وينبغي أن تكون صفة العقرب بكواكبها

<شكل> شبكة المعقرب

(أسماء البروج) — أصل الذنب، شمالي النعامات[14] ، عين قيطس، رأس قيطس، الجذما، رجل الجوزاء[15] ، ذنب الأرنب[16] ، عبور، غميصا، وسط الشجاع، دبران[17] ، جناح الغراب، أعزل، شمالي الغفر[18] ، نيّر الغفر، جنوبي الزبانا، قلب العقرب، رأس الحوّاء، السابق الثاني، نيّر الذابح، طائر، فم الفرس، نيّر الخباء، ذنب قيطس[19]

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[10] داوائر **D** [11] فهما **P,D** [12] رحمة الله عليه add. **D** [13] فلك البروج] قطب فلك البروج **P,D**
[14] In **D** the labels of many star-pointers are mixed up: see Appendix 3. [15] رجل جوزاء **P,D**
[16] ذنب أرنب **P,D** [17] دابران **P,D** [18] شمالي غفر **P**; لتال عمر **D** [19] Illeg. **D**

<**ملاحظة**> هذا الآلة آفاقية تعمل في سائر البروج من عرض ك ك إلى عرض س ومن عرض س إلى فط تعمل في بعض البروج وتبطل في البعض وهي بخيط في المركز

D:61r P:3v **البـــاب لج في معرفة وضع الأصطرلاب الجنوبي المتكافئ** وهو أن تدير دائرة وتربّعها وأدر المدارات الثلاث كما تقدّم وخذ من الجدول الجنوبي المستخرج من جداول الدائر بقدر ما بحيال كلّ مقنطرة وعلّم بقدره في مدار السرطان والجدي وكذلك الحمل واجمع الثلاث علامات فهي[1] قسي المقنطرات فاكتب عليها أعدادها وأمّا السموت فكما تقدّم وتركها[2] أصلح <من وضعها> وأحسنه أن[3] يعلم من الدائرة السمتية المتقدّم ذكرها أو من الحجرة من الباب المذكور

<**شكل**> صفيحة الأصطرلاب الجنوبي المتكافئ

استنبط هذا الشكل مصنّف هذا الكتاب

D:61v P:4r **وأمّا الشبكة** وهو أن تدير دائرة قدر أكبر الدوائر في الصفيحة وتربّعها ثم تأخذ ممّا[4] بين مدار السرطان ومدار الجدي على خطّ تربيع الصفيحة من جهة العلاقة وأسفلها وانقل البركار بفتحته حتى تضعه على خطّ تربيع الشبكة فأدر دائرة كاملة فهي منطقة البروج وينبغي أن يكون بمنطقتين ثم أقم[5] المصطرة على مطالع كلّ برج بالفلك وعلى مركز الشبكة ومدّ خطًّا بين القوسين[6] التي تحوز أسماء البروج ثم ضع الكواكب كما تقدّم ببعدها ومطالعها وجهة أبعادها وينبغي أن تكون الكواكب الشمالية مرسومة في المنطقة الشمالية والجنوبية في المنطقة الجنوبية واكتب على كلّ منها[7] اسمه

<**شكل**> شبكة الجنوبي المتكافئ

(أسماء البروج: مرّتين) — <التسطيح الشمالي:> الرامح[8] ، رأس الحوّاء، عبور، النسر الطائر — <التسطيح الشمالي:> هنعة، ذنب قيطس[9] ، غميصا، متن الفرس

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[1] فهما **P,D** [2] تركه **P,D** [3] وأحسنه أن] وأحسن ما **P,D** [4] من ما **P,D** [5] اضع **P** [6] قوسي **P,D** [7] منهما **P,D** [8] om. **D** [9] om. **D**

رجل البركار على خطّ التربيع والرجل الأخرى على نقطة سمت الرأس ولا تزال تتقارب وتتباعد برجله حتى تجمع قطبي التسطيح ونقطة سمت الرأس فهي دائرة أوّل السموت فمدّ خطّ مشرقها ومغربها وانقل البركار حتى تضعه على نقطة سمت الرأس وعلى كلّ علامة منها[11] فاثبت رجله على خطّ مشرق الدائرة السمتية وأدر برجله قوسًا من سمت الرأس إلى طرفي تلك الدائرة واكتب عليها أعدادها فقد كملت هذه[12] الصفيحة

<شكل> الصفيحة السمتية لعرض لو جنوب وشمال

البـــاب لب في معرفة وضع المُبَكَّش

D:60v P:3r

وهو أن تدير دائرة وتربّعها ثم تدير دائرة الحمل والسرطان والجدي كما تقدّم واقسم الدائرة الكبرى شس قسمًا ⌈كلّ ربع ص⌉[1] ثم ضع المصطرة على ل من جهة المشرق وعلى المركز ومدّ خطًّا وهميًا[2] ثم ضع[3] البركار على خطّ المغرب ورجله على موضع تقاطع الخطّ الوهمي لدائرة السرطان وأدر برجله قوسًا إلى الدائرة الكبرى موضع التقاطع لنقطة المغرب إن أمكن ذلك وإلّا تتأخّر وتتقدّم برجل البركار حتى تجمعها[4] ثم ضع المصطرة على أقسام الدائرة الكبرى وعلى المركز وعلّم على حرف المصطرة على القوس وضع[5] رجله في المركز وأخرى على كلّ قسم منها[6] وأدر قسي إلى خطّ الشمال ثم اقسم مدار السرطان والجدي والحمل كلّ منها[7] قف ثم اجمع الثلاث علامات بالبركار واكتب عليها أعدادها وقد[8] تعمل[9] في الربع الشرقي الشمالي جيوب مبسوطة وتكتب عليها عدد قوس الربع على خطّ المشرق وهو الأصل لهذه الآلة

<شكل> شكل المبكّش وهو شكل حسن[10]

قسي الفضلات المخالفة لجهة العرض — قسي الفضلات الموافقة لجهة العرض — جدي، مدار الحمل، السرطان — مشرق — مغرب

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[11] منهما **P,D** [12] هذه om. **D** [1] ⌈…⌉: **P** marg.; ثم كل ربع ص **D** [2] وهمي **P** [3] اضع **P** [4] تجمعهما **P,D** [5] اضع **P** [6] منهما **P,D** [7] منهما **P,D** [8] وقد وقد **D** [9] يعمل **P,D** [10] وهو شكل حسن om. **P**

<شكل> شكل الزرقالة وهي آلات آفاقية[8]

قطب معدّل النهار الشمالي — قطب معدّل النهار الجنوبي — قطب فلك البروج الشمالي — قطب فلك البروج الجنوبي

D:50v P:18r **البـــاب لَ في معرفة وضع الأصطرلاب الرصدي وهو ذات الحلق** وذلك أن تدير دائرة وتقسمها بأربعة أقسام متساوية كلّ قسم صَ قسمًا واكتب أعدادها ثم تدير دائرة أصغر من تلك الدائرة وافعل كذلك ثم تدير قوسًا في وسطها وهو موضع الدائرة الوسطى فإنّه في الآلة دائرة كاملة وهو في الورق ما يُتصوّر إلّا كما تراه وهذا ليس يُعلَم من جهة الجداول وإنّما هو بطريق الهندسة والقسمة

وما عملناه في كتابنا إلّا لكون أنّه أصل لسائر ما شكّلناه فإنّ الآلات المتقدّم بسطها محتالة (؟) على الميل والبعد والمطالع فإذا لم نعلم ذلك احتجنا إلى هذه الآلة الرصدية فإنّ البعد ومطالع إذا كانا مجهولين لا غناء لنا عن هذه الآلة الرصدية وهي سبع حلقات وقيل تسعة كلّ واحدة أضيق من الأخرى وفتحتها كالكرة

<شكل> ذات الحلق ويسمّى الرصدي أيضًا[9]

D:60r P:18v **البـــاب لاَ في معرفة وضع الدائرة السمتية**

وهي أصل لجميع ما وضعناه من الآلات فإنّ أكثرها لم تكن صفيحته مسمّتة فإمّا أن يُعلم السمت من هذه أو من دائرة الحجرة وهذه الصفيحة تنبغي أن تكون في بعض صفائح الأصطرلاب فإذا أردت وضعها فأدر دائرة واعلم الدائر من الجدول لكلّ عشرة من السمت وعلّم بقدره على الدائرة الكبرى وخذ فتحة بالبركار بقدر بعد سمت الرأس من مركز الصفيحة وضع رجله في مركز الصفيحة والرجل الأخرى على خطّ تربيع الدائرة فهو موضع نقطة سمت الرأس وضع[10]

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[8] وهي آلات آفاقية] وهي من الآلة الآفاقية **D**   [9] أيضا om. **P**   [10] اضع **P**

مقنطرة بعد الكوكب وانقله حتى تضعه في مركز الشبكة والرجل الأخرى حيث وقعت على خطّ مطالع الكواكب فهو موضعه

<شكل> شبكة العقابي

(أسماء البروج) — <التسطيح الشمالى:> أعزل — <التسطيح الجنوبى:> يد الجوزاء النسر الطائر، صرفة، رأس الحواء، النسر الطائر، سرة[4] الفرس

D:59r P:35v

البـــاب كطَ في معرفة وضع الزرقالة (!)[5]

وهي وضع الشكّازية مركّب فوق شكّازية لكنّها مخالفة لقسي الأخرى إذا أردت ذلك أدر دائرة وربّعها بخطّين وتضع المصطرة على نقطتي تقاطع أحد الخطّين لتلك الدائرة وعلى كلّ قسم منها[6] وعلّم على الخطّ الآخر المقاطع لحرف المصطرة وافعل ذلك إلى أن تُكمل جميع أعداد قسمة الدائرة ثم ضع رجل البركار على خطّ العلامات وتتقدّم وتتأخّر حتى تجمع تلك العلامات وقسمة الدائرة إن شئت خمسة خمسة أو ستّة ستّة أو غير ذلك فقد كملت المدارات وكذلك تفعل بالمرّات

< ... > ثم تقسم هذه الدائرة بقدر قسمة الدائرة الأولى وتفعل ما فعلت أوّلًا ويكون بين خطّ الطول وخطّ التربيع أعني بين القطبين بقدر الميل الأعظم واكتب أعداد المدارات وأعداد المرّات وينبغي أن يكون عليها خطّ الأفق المائل وهو مقسوم بقدر تلك القسمة

وتكتب أسماء البروج على خطّ الطول في الشكّازية أو على الأفق المائل وهذه الآلة لا تُكتب عليها أسماء البروج فإنّ درجة الشمس تُعلم منها من غير كتابة وقد يوضع على ظهر هذه الآلة المشهورة بالمعترضة ورسمها من جهة الهندسة أو الحساب[7] وإن شئت من هذا الكتاب وسوف نذكره إن شاء اللّه تعالى

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[4] صرة **P**; صفة **D** [5] الزرقالة **D** (with the ر written above the ز); الزقالة **P** [6] منهما **P,D**
[7] أو الحساب om. **D**

D:57v P:20r **وأمّا الشبكة** فهو أن تدير دائرة وتربّعها ثم اعلم موضع قطب فلك البروج وضع رجل البركار فيه ثم أدر دائرة وهمية من جهة اليمين واليسار وضع المصطرة على مطالع كلّ برج لمفرده وعلى المركز وعلّم <ثم مدّ> خطًّا بين قوسين[10] ليحوز أسماء البروج وأمّا الكواكب فضع رجل البركار في مركز الصفيحة والرجل الأخرى على مقنطرة بعد الكوكب وانقله حتى تضع رجله في مركز الشبكة والأخرى حيث وقعت على خطّ مطالع الكوكب فهو موضعه

<شكل> شبكة الضفدعي

(أسماء البروج) — <التسطيح الشمالى:> دبران، رجل الجوزاء، الشعرى الغميصا، الفرد، أعزل، دلفين — <التسطيح الجنوبى:> صرفة، زبانا، رأس الحوّاء، النسر الطائر، سرة[11] الفرس

D:58v P:20v البــــاب كح في معرفة وضع الأصطرلاب العقابي المستنبط

وهو أن تدير دائرة وربّعها وأدر المدارات الثلاث ثم خذ من جدول المقنطرات بقدر ما بحيال كلّ مقنطرة للحمل وخذ بمثله من قسمة دائرة الحمل وافعل ذلك للمنقلبين واجمع العلامات الثلاث من داخل دائرة الحمل وخارجها إلى أن تُكمل المقنطرات وأمّا السموت فتركها أولا <من وضعها> وأحسنه أن[1] يعلم من الدائرة السمتية أو من الحجرة من <أحد> أبواب الرسالة

<شكل> صفيحة العقابي لعرض لو[2]

استنبطه مصنّف هذا الكتاب

D:58r P:35r **وأمّا الشبكة** فهو أن تدير دائرة وتربّعها ثم اعلم موضع قطب فلك البروج وضع رجل البركار فيه ثم أدر دائرة وهمية من جهة اليمين واليسار وضع المصطرة على مطالع كلّ برج لمفرده وعلى المركز وعلّم <ثم مدّ> خطًّا بين قوسين[3] ليحوز أسماء البروج وأمّا الكواكب فضع رجل البركار في مركز الصفيحة والأخرى على

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[10] قوسي **P,D** [11] صرة **P**; صرفة **D** [1] وأحسنه أن] وأحسن ما **P,D**

[2] The illustration on **D** furthermore bears this line of prayer, in a later hand: يا مولائي يا واحد يا مولائي يا دائم يا علي يا من (؟) كم (؟) [3] قوسي **P,D**

D:46v
P:2r

البـــاب كو في معرفة وضع الأفقات ويسمّى الآفاقية

وأدر دائرة وربّعها ثم اعلم نصف الفضلة لرأس أحد المنقلبين لعرض عشرة عشرة أو غير ذلك من جداول أنصاف الفضلات وخذ بعدده من أقسام الدائرة الكبرى وعلّم علامات الفضلات وضع المصطرة على كلّ علامة وعلى مركز الصفيحة وعلّم على حرف المصطرة في دائرة الحمل ثم ضع المصطرة على قطب التسطيح وعلى علامات الحمل وعلّم على حرف المصطرة لخطّ التربيع من الأربع جهات ثم ضع رجل البركار على أحد خطوط التربيع ورجله الأخرى على العلامات الواقعة على خطّ التربيع وعلى قطب التسطيح وأدر قوسًا من خطّ التربيع إلى الدائرة الكبرى وإن شئت فاجمع علامات نصف الفضلة وقطبي التسطيح فهو أسهل من الأوّل

<**شكل**> شكل الأفقات من بلدٍ لا عرض له إلى عرض ص

D:57r
P:2v

البـــاب كز في معرفة وضع الأصطرلاب الضفدعي المستنبط

وهو أن تدير دائرة وربّعها ثم أدر المدارات الثلاث ثم خذ من جدول المقنطرات بقدر ما يحصّ كلّ مقنطرة للحمل وخذ بمثله من قسمة دائرة الحمل ثم افعل ذلك للمنقلبين واجمع العلامات الثلاث من داخل دائرة الحمل وخارجها إلى أن تُكمل المقنطرات فاكتب عليها أعدادها وأمّا السموت فتركها أولا <من وضعها> وأحسنه أن[8] يعلم من الدائرة السمتية أو من الحجرة من <أحد> أبواب الرسالة الآتية

<**شكل**> صفيحة الضفدعي

استنبط مصنّف هذا الكتاب[9]

[8] وأحسنه أن] وأحسن ما **P,D** [9] Text om. **D**

وأمّا الكواكب فتارّة موضع في الشبكة وتارّة في الصفيحة على ما يراه الواضع وأحسن وضعها في الشبكة وذلك ببعدها وجهته ومطالع كلّ منها[12] واكتب على كلّ كوكب اسمه المعلوم

<شكل> شبكة المبطّخ[13] للبيروني

(أسماء البروج) — نيّر الظباء (؟)، رأس الحوّاء[14] ، طائر، الواقع (؟)[15] ، فم الفرس، أصل ذنب قيطس

البـــاب كه في معرفة وضع الأصطرلاب الأكري D:46r P:1v

وهو أن تدير دائرة في وسط الكرة[1] ثم تعلّم قطبي تلك[2] الدائرة وتعلّم الدائر لكلّ مقنطرة من الجداول ويكون العمل[3] لرأس الاعتدال ببلد لا عرض له فوجدنا الدائر موافقًا لعدد المقنطرة فاقسم خطّ القطبي بمائة وثمانين[4] قسمًا متساويًا وضع رجل البركار في مركز الكرة ورجله الأخرى على كلّ قسم منها[5] وأدر برجله دائرة فهي مقنطرة بعينها فإن أردت السمت فخذ خطًّا شعاعيًا من قسمة الدائرة الكرة إلى المركز فقد وضعت السموت فاكتب على كلّ منها[6] عدده وهذا وضع الكرة المنتصبة على الكرسي وأمّا شبكة هذا الاصطرلاب فهي كالعادة لكنّها مقببة فلا[7] يمكن تصويرها

واعلم أن الكرة لا يحتاج مقنطرة ولا سموت فإنّ قوس الزوال أغنى عن المقنطرات وقطعة القوس المتحرّكة على وجه الكرة أغنت عن السموت وإنّما يحتاج إلى قسي البروج ودائرة معدّل النهار وقطبهما ودائرة الأفق المقسومة على الكرسي شس كلّ ربع منها ص

<شكل> الأسطرلاب الأكري

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[12] منهما P,D [13] المطخ D [14] Illeg. D [15] om. D [1] الأكرة P [2] الكرة ثم تعلم قطبي تلك illeg. D [3] العمل om. D [4] ثمانون P [5] منهما P,D [6] منهما P,D [7] فلا illeg. P

D:45r
P:23v

البـــاب كدَ في معرفة وضع الأصطرلاب المبطّخ[1]

أدر دائرة وهي دائرة الجدي وربّعها بخطّين وأدر الثلاث دوائر كما تقدّم وهي[2] المنقلبين والاعتدال واعلم فضل[3] الدائر من الجدول لارتفاع عدد المقنطرة وعدّ بقدره من كلّ مدار من الثلاثة مبتدئاً من العلاقة <وعلّمه عليها> وضع رجل البركار على تلك العلامات الثلاث ورجله الأخرى على خطّ العلاقة وتتأخّر وتتقدّم برجله حتى تجمع تلك العلامات من مدار أحد المنقلبين إلى مدار الاعتدال فاكتب عدد المقنطرة وعرض البلد الذي اخترته[4] وأمّا السموت فقد تقدّم ذكرها وأحسنه من دائرة الحجرة أو الصفيحة السمتية المذكورة

وأمّا الساعات فاعلم ارتفاع الساعات من جداول الدائر أو من الجدول الآتي وعلّم على كلّ مدار من الثلاثة بقدر الثلاث في المقنطرات واجمع بالبركار الثلاث علامات فهي[5] قسي الساعات وتركها[6] أولا

وقد وجدته مشكلًا عن هذا الشكل في البيروني وفيه خلاف بين العلماء فاستنبطتُ هذا لمّا رأيت الخلاف بينهم ووجدته بشبه الأكرى وفيه قوس صفة الأفق ولا هو من أشكال الصفائح ولا صفة العمل بها[7] وقد أخذ عليه بعض فضلاء هذا الفنّ وحظّ على من استنبطه فتركته في كتابي هذا وعوّضته بهذا الشكل

<شكل> صفيحة المبطّخ[8] لعرض لوَ

استنبط هذا الشكل مصنّف هذا الكتاب عوضًا عن صفيحة البيروني

D:45v
P:1r

وأمّا وضع شبكته خذ فتحة بقدر ما بين[9] المنقلبين[10] على خطّ أحد التربيع وانقله بفتحة وأدر قطعة قوس ثم خذ فتحة بقدر ما بين القطبين وضع رجله في مركز قطعة القوس والرجل الأخرى حيث وقعت على خطّ موازي لمركز القوس فهو قطب الصفيحة ضع المصطرة عليه وعلى مطالع كلّ برج بالفلك وعلّم على القوس علامة[11] وأدر قوسًا <آخر دون القوس الأوّل> يحوز أسماء البروج

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[1] المسطخ **D** [2] وهما **P,D** [3] فضل over the line **P** [4] اختوته **D** [5] فهما **P,D** [6] وتركهم **P,D**
[7] بهما **P,D** [8] المطبخ **D** [9] بقدر ما بين smudged **P** [10] المنقلبين marg. **P** [11] على القوس علامة] على علامة القوس **P,D**

D:44r **البـــاب كج في معرفة وضع الأصطرلاب الهنّابي**

أدر دائرة وربّعها وأدر الثلاث المدارات[2] وافعل كما فعلت في الجنوبي المتقدّم وعلّم على خطّ التربيع من جانبي المركز واجمع المقنطرات التي[3] علّمتها[4] من حساب جدول المقنطرات الجنوبية وشكله قعر (؟؟) هنّاب من مقنطرة المعترض وهذا الشكل ٩ شبكة استنبطها[5] مصنّف هذا الكتاب في التأريخ المذكور[6]

<شكل> صفيحة الهنّابي لعرض لو

استنبط هذا الشكل مصنّف هذا الكتاب

D:44v P:23r **وأمّا وضع شبكته** <فهو أن تدير دائرة وتربّعها ثم> تعلم موضع قطب فلك البروج وأدر دائرتين وهميتين وعلّم على مطالع كلّ برج وضع المصطرة على المركز وعلى العلامة ومدّ خطًّا وهميًا ثم ضع[7] رجل البركار في قطب فلك البروج وأدر برجله قوسًا فهو المطلوب وأمّا وضع الكواكب[8] فببعدها وجهة بعدها ومطالع كلّ منها[9] كما تقدّم واكتب على كلّ كوكب اسمه المعلوم

<شكل> شبكة الهنّابي[10]

(أسماء البروج) — <التسطيح الشمالى:> ذنب قيطس، قرن الحمل، برشاوش، يد الجوزاء، الغميصا، الفرد سهيل، الاعزل، مرفق الجاثي، رأس الحوّاء، سرة[11] الفرس — <التسطيح الجنوبى:> الصرفة، الطائر، شمالي الكرب

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[2] Elsewhere the text has consistently الثلاث مدارات but this form is also correct. [3] الذي **MS** [4] علمتهم **MS** [5] استنبطه **MS** [6] This last sentence is unhappy. One should probably read ... وهذا الشكل هو الشبكة التاسعة من التي [7] اضع **P** [8] الكوكب **P**,**D** [9] منهما **P**,**D** [10] Twice repeated in **P** [11] صرة **P**,**D**

بين قوسين[9] ليحوز أسماء البروج وأمّا الكواكب فببعدها ومطالعها كما تقدّم واكتب على كلّ كوكب اسمه المشهور وشكل الشبكة بشكل يشبه الزحلفاة[10] وأحسنه أن تكون كواكبًا

<شكل> شكل شبكة الأصطرلاب الزحلفي[11]

(أسماء البروج) — <التسطيح الشمالي:> جناح الغراب، الاعزل، الطائر، ذنب قيطس — <التسطيح الجنوبي:> قرن الحمل، رجل الجوزاء، متن الفرس

الباب كب في معرفة وضع الأصطرلاب الجاموسي **D**:43r

وذلك أن تدير دائرة وربّعها وتقسم الدائرة الكبرى تسعين قسمًا متساويًا ثم خذ من الجداول بقدر الدائر لكلّ مقنطرة أعني من الجدولين الشمالي والجنوبي المنقلبين والاعتدال وعلّم على المدارات الثلاث واجمع العلامات من جهة اليمين واليسار إلى أن تكمّلت المقنطرات واكتب عليها أعدادها وأمّا السموت فكما تقدّم وأحسنه أن يُعلم من الحجرة

<شكل> صفيحة الجاموسي

وأمّا الشبكة وهو أن تدير دائرة وتربّعها ثم اعلم موضع قطب فلك البروج وضع **D**:43v
رجل البركار في موضع القطب وأدر دائرة وهمية وأدر قوسًا من الدائرة الكبرى إلى مطالع آخر الدلوأ وكذلك تفعل من جانب الآخر ثم انقل رجله بفتحته أيضًا في خطّ التربيع وافعل كذلك من الجهات الأربع واكتب على كلّ برج منها[1] اسمه وأمّا الكواكب فاستخرج مطالعها وبعدها من الجدول المطالع وضعها كما تقدّم واكتب على كلّ كوكب اسمه المعلوم

<شكل> شكل شبكة الأسطرلاب الجاموسي

(أسماء البروج) — <التسطيح الشمالي:> أصل ذنب قيطس، يد الجوزاء، جناح الغراب، الاعزل، الطائر — <التسطيح الجنوبي:> لسان الشجاع، مرفق الجاثي، شمالي الكرب

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[9] قوسي **MS** [10] *Sic* **D**. [11] *Sic* **D** [1] منهما **MS**

<شكل> صفيحة الثوري لعرض لو

D:41v P:32r **وأمّا وضع الشبكة** أدر دائرة وربّعها ثم اعلم موضع قطب فلك البروج وضع رجل البركار عليه وأدر برجله الأخرى دائرة وهمية ثم انقله بفتحته إلى الخطّ الآخر وأدر برجله دائرة وهمية ثم ضع[2] المصطرة على مطالع كلّ برج وعلى المركز ومدّ خطًّا وهميًا ثم ضع[3] رجله في المركز وأدر برجله <الأخرى> قوسًا آخر تحت القوس الأوّل إلى الخطّ الوهمي <الذي> يحوز بين البروج واكتب على كلّ برج اسمه وأمّا الكواكب فببعدها ومطالعها واكتب على كلّ كوكب اسمه وتشكّل هذه الشبكة بشبه الثور وأحسنه أن تكون[4] <في> قرنيه كوكبان

<شكل> شكل شبكة الأصطرلاب الثوري

(أسماء البروج) — نيّر النعامات، رجل الجوزاء، الغميصا، منقار الغراب، ذنب الشجاع، شمالي الزبانا، الحوّاء، الطائر، متن الفرس، ذنب قيطس

D:42r P:32v **البـــاب كا في معرفة وضع الأصطرلاب السحلفي[5]**

أدر دائرة وربّعها وأدر الثلاث مدارات ثم خذ من الجدول بقدر الدائر لكلّ مقنطرة وضع المصطرة على أقسام الدائرة الكبرى بقدر الدائر لتلك المقنطرة وعلى المركز وعلّم على مدار كلّ منها[6] فإذا تكمّلت علامات المقنطرات اجمعها[7] بالبركار داخل دائرة الحمل وخارجًا عنها فإذا كُمِل عدد المقنطرات اكتب عليها أعدادها وأمّا السموت فكما تقدّم وأحسنه من الحجرة

<شكل> صفيحة الزحلفي[8] لعرض لو

D:42v **وأمّا الشبكة** أدر دائرة وربّعها ثم اعلم موضع قطب فلك البروج وضع رجل البركار في ذلك الموضع ثم أدر دائرة وهمية <دون الدائرة الأولى> من جهة اليمين واليسار وضع المصطرة على مطالع كلّ برج بمفرده وعلى المركز ومدّ خطًّا

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[2] اضع **P** [3] اضع **P** [4] Correct would be تكونا [5] *Sic* **P**,**D**. On this word see p. 41 of the introduction. [6] منهما **P**,**D** [7] اجمعهما **P**,**D** [8] *Sic* **P**,**D**

D:40r

البـــاب يط في معرفة وضع الباطي

أدر دائرة وربّعها ثم خذ فتحة بقدر فضل الدائر لكلّ مقنطرة للمدارات الثلاث واجمعها[7] داخل دائرة الحمل من جهة العلاقة وأسفلها كما وضعت المقنطرات الجنوبية فاجمعها[8] من خارج دائرة الحمل كما وضعت المقنطرات الشمالية المتقدّم ذكرها فقد كُمِلت الصفيحة إن شاء اللّه تعالى

<شكل> صفيحة الباطي لعرض لو

مشرق، مغرب

D:40v
P:31r

وأمّا وضع الشبكة أدر دائرة وربّعها ثم خذ فتحة بقدر نصف قطر منطقة فلك البروج وأدره دائرتين وهمية (!) ثم ضع المصطرة على المركز وعلى مطالع كلّ برج بالفلك وعلّم على تلك الدائرتين واكتب بينهما أسماء البروج وأمّا الكواكب فببعدها ومطالعها كما تقدّم واكتب على كلّ منها[9] اسمه وجهته

<شكل> شبكة الباطي

(أسماء البروج) — الاعزل، شمالي الزبانا، منكب الحوّاء، [رأس ا]لحوّاء، عقاب[10] ، النسر الطائر، متن الفرس، ثاني الشرطين، يد الجوزاء، العبور، الفرد سهيل، جناح الغراب

D:41r
P:31v

البـــاب ك في معرفة وضع الأصطرلاب الثوري

أدر دائرة وربّعها وخذ من جدول المقنطرات الشمالية ما بحيال كلّ مقنطرة للحمل والسرطان وعلّم على كلّ مدار منهما بقدر الدائر مبتدئاً من الأفق ثم خذ من جدول المقنطرات ما بحيال كلّ مقنطرة للجدي[1] وعلّم على مداره أيضًا ثم ضع رجل البركار على خطّ العلاقة واجمع العلامات الثلاث واكتب على المقنطرات أعدادها وأمّا وضع السموت فهو كما تقدّم وأحسنه أن يُعلم من دائرة الحجرة أو من الصفيحة السمتية الآتي ذكرها

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[7] واجمعهما **MS** [8] فاجمعهما **MS** [9] منهما **P,D** [10] In **P** the names حوا and عقاب are smudged on the pointers, so the copyist has written them a second time below the circumference. On **D** the same star-pointers are unlabelled, but the star names appear below the circumference exactly as in **P**! [1] الجدي **P,D**

D:39r **البـــاب يحَ في معرفة وضع الأصطرلاب الزورقي**

اعلم أن صفيحته منسوبة إلى شكل الشبكة وذلك أن تدير دائرة وتربّعها بخطّين وتضع دائرة الاعتدال ودائرتي المنقلبين وتعلّم موضع المقنطرات من جدول الدائر المذكور أوّلًا وتضع رجل البركار في قطب التسطيح وعلّم كلّ علامة من المقنطرات وعلّم على جنب المصطرة المقاطع لخطّ العلاقة وخطّ قوس الأفق من جهة العلاقة وأسفلها واجمع تلك العلامات فهي[4] علامات المقنطرات فاكتب عليها عددها من جهة العلاقة وأسفلها وأمّا السموت فتركها أولا من وضعها فافهم تصب

<شكل> صفيحة الزورقي لعرض لوَ

مشرق، مغرب

D:39v **وأمّا وضع الشبكة** فاعلم موضع قطب فلك البروج وضع رجل البركار فيه والرجل الأخرى على الدائرة الكبرى وأدر قوسًا في أحد الأرباع ثم انقل البركار بفتحته وضع رجله في موضع القطب من الجانب الآخر وافعل كذلك ثم انقله بفتحته أيضًا وضع رجله في موضع القطب من الجانب الآخر وأدر قوسًا ثم انقله بفتحته أيضًا وافعل كذلك وأدر قوسًا فقد كُمِلت منطقة البروج فاكتب عليها أسماء البروج وأمّا الكواكب فببعدها ومطالعها كما تقدّم

<شكل> شكل شبكة الأصطرلاب الزورقي شكل حسن

(أسماء البروج) — <التسطيح الشمالى:> يد الجوزاء، نيّر الهنعة، جناح الغراب[5] ، الاعزل، شمالي الزبانا، الواقع، منكب الفرس — <التسطيح الجنوبى:> ثاني الشرطين، جنوبي النعامات[6] ، الفرد سهيل، الطائر، متن الفرس

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[4] MS فهما [5] MS جناح غراب [6] MS جنوبي النعات

[9] (أسماء البروج) — رأس <ذات> الكرسي، ذنب الحوت، بطن الحوت، رجل المسلسلة، نيّر البطين، الغول، [ال]كفّ الجذما، ركبة برشاوس، رابع النهر، العيّوق، قرن الثور، يد الجوزاء، معصم الأعنة، العبور، سهيل اليمن، نيّر التؤمان[10] ، أوّل الذراع الشامي، رقبة الدبّ ، بطن شجاع، قلب الاسد، القفزة الثالثة، أوّل الخرتان[11] ، وسط الشجاع[12] ، جنوبي فخذ الدبّ، كبد الاسد، آخر العوّاء، الرامح ، منكب العوّاء <الايسر>، عنق الحيّة، فخذ العوّاء، الفكّة، منكب العوّاء <الايمن>، عين التنّين، معصم الجاثي، الواقع، منقار الدجاجة، الطائر، مرفق الدجاجة، ذنب الدجاجة وهو الردف، صدر الدجاجة، قلنسوة الملتهب، منكب الفرس، فم الحوت، وسط كفّ المسلسلة، جناح ، سرة[13] الفرس

البـــاب يو في معرفة وضع الأصطرلاب الشقائقي وشبكته

D:38r
P:24v

أدر دائرة وربّعها وأدر مدار الاعتدال والمنقلبين وافعل كما فعلت بمقنطرات الشمالي الأوّل المستخرج من الجدول واجمع العلامات الثلاث على المدارات المذكورة من العلاقة وأسفلها وكذلك على خطّ المغرب

<شكل> صفيحة الشقائقي وشبكته هي شبكة الآسي والمتكافئ وقد تقدّم وضعها

البـــاب يز في معرفة وضع الأصطرلاب المجمّد ويسمّى مجمّد لكون كواكبه جامدة في الصفيحة

D:38v

وذلك أن تدير دائرة وتربّعها وتضعه كما وضعت الشمالي أوّلًا وأمّا الكواكب والمنطقة فترسمها[1] كما تقدّم وجميع كواكبه بين الساعات ومنطقة البروج فوق المقنطرات وأسفلها

<شكل> صفيحة المجمّد وشبكته العضادة

عرض لو — أولة، ثانية ... حادية عشر — (أسماء البروج) — ذنب الحوت رأس قيطس[2] ، دبران، العيّوق، رجل الجوزاء، يد الجوزاء، عبور، غميصا، الفرد، قلب الاسد، بطن الشجاع، منقار الغراب، ذنب قيطس[3]

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[9] The diagram is incomplete and lacking inscriptions in **D**. It is drawn upside-down in **P**.
[10] نير الومان **MS** [11] الخزبان **MS** [12] الشاع **MS** [13] صرة **MS** [1] ترسمهم **MS** [2] رأس قيطش **MS** [3] ذنب قيطش **MS**

دائرة السرطان[2] ثم خذ بقدر نصف قطر الأفق <الأبعد> وهو و كد المعلوم أوّلًا وضع رجل البركار في المركز وعلّم برجله الأخرى إلى جهة العلاقة ثم ضع رجل البركار على خطّ نصف النهار وتتقدّم وتتأخّر حتى تجمع برجله الأخرى قطبي التسطيح وعلامة للأفق وأدر برجله الأخرى دائرة كاملة فهي الأفق ثم علّم في المدارات الثلاثة بقدر فضل الدائر من الجدول الشمالي واجمع العلامات إلى أن تكمّل المقنطرات الشمالية ثم تفعل بالمقنطرات الجنوبية كذلك نهايتها إلى السرطان

<شكل> جنوبي شمالي وشبكته برسمها[3]

استنبطه مصنّف هذا الكتاب[4]

بيان وضع الشبكة أدر دائرة ⌉ بقدر أكبر دوائر في الصفيحة ⌈[5] وربّعها ثم خذ فتحة بالبركار بقدر ما بين دائرتي المنقلبين مخالفًا في الجهة على خطّ التربيع في الصفيحة المرسومة ثم انقله بفتحته[6] إلى قطب فلك البروج وأدر برجله دائرة بعد أن تعلّم موضع دائرتي المنقلبين في الشبكة فما كان بينهما فهو موضع قطب فلك البروج ثم أدر دائرة دونها لتحوز أسماء البروج وأمّا الكواكب فضع المصطرة على مطالع الكوكب ثم ضع البركار في مركز الصفيحة ورجله الأخرى على مقنطرة بعده في جهته وانقله بفتحة أيضًا إلى مركز الشبكة والرجل الأخرى حيث وقعت على جنب المصطرة فهو موضعه فاكتب عليه اسمه المعلوم وينبغي أن تكون الكواكب الشمالية البعد خارجة عن المنطقة والكواكب الجنوبية البعد[7] داخلة في المنطقة كما صوّرناها هنا وهي أكثر كواكبا D:85v P:24r

<شكل> شكل شبكة الجنوبي الشمالي[8]

[2] الجدي **P**,**D** [3] Caption om. **D** [4] Text om. **D** [5] ⌈…⌉ marg. **P** [6] بفتحة **P**,**D** [7] البعد om. **D** [8] الجنوبي الشمالي] الشمالي الجنوبي **P**; caption om. **D**

فإذا أردت ذلك فهو وضع الشمالي الجنوبي بعينه وقد تقدّم ذكرهما فإذا جمعت كلّ منهما في صفيحة واحدة حصل هذا الشكل فإن شئت أن قسمته فافعل ما تقدّم في وضع السموت وإن شئت فارسم له صفيحة السمت خاصّة وهي تعمل لسائر الأصطرلابات سيأتي ذكرها إن شاء اللّه تعالى

<شكل> شكل صفيحة الأسطرلاب الآسي — شكل صفيحة الأسطرلاب المطبّل

D:84v P:22r **بيان وضع شبكة المطبّل** أدر دائرة وتربّعها ثم اعلم موضع قطب فلك البروج وضع رجل البركار في موضع القطب وأدر برجله دائرة من خطّ التربيع إلى خطّ الآخر وتفعل من جهة الأخرى كذلك فهي منطقة فلك البروج[8] ثم ضع المصطرة على مطالع كلّ برج وعلى قطب الشبكة وخطّ خطًّا فهو علامة ذلك البرج وأمّا الكواكب فوضعها بمطالعها وببعدها كما تقدّم فافهم تصب إن شاء اللّه تعالى

<شكل> شبكة المطبّل جنوبي شمالي

(أسماء البروج) — <التسطيح الشمالى:> ذنب الحوت، ناطح[9] ، الغول، الدبران، رجل الجوزاء، العبور، سهيل الفرد[10] ، الصرفة، أعزل، رامح، عنق الحيّة، فكّة، رأس الحوّاء، الواقع[11] ، الطائر[12] ، الردف، منكب الفرس[13] — <التسطيح الجنوبى:> قلب الأسد[14] ، ذنب الطائر[15]

D:85r P:22v **البـــاب يه في معرفة وضع الأصطرلاب الجنوبي الشمالي من غير أن تتعرّض إلى النظر في الشبكة**

وهو أن تدير دائرة وتربّعها ثم تقسم أحد التربيع س لب دقيقة المعلومة من الباب و في وضع الجنوبي الكامل ثم خذ من تلك القسمة بقدر نصف قطر الاعتدال وهو يط لط دقيقة وأدر بالبركار دائرة فهي دائرة الاعتدال ثم خذ يب ند دقيقة <وأدر دائرة> فهي دائرة الجدي[1] ثم خذ ل <وأدر دائرة> فهي

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[8] منطقة البروج **P** [9] الذنب **D** [10] الفرد **P** [11] واقع S [12] تائر S [13] منكب فرس **D**
[14] قلب اسد **P** [15] ذنب طائر **P**; ذنب الجدي **D** [1] السرطان **P,D**

وأمّا السمت فكما تقدّم وما تركناه إلّا أنّ الآلات تُظلم <و> أحسن ما يُعلم السمت من هذه الأشكال كلّها <هو>[3] من دائرة الحجرة وسيأتي ذكره في الرسالة إن شاء اللّه تعالى

<شكل> صفيحة الأصطرلاب الشمالي المتكافئ[4]

عرض لو — مشرق، مغرب[5]

D:83v **بيان شبكة الشمالي المتكافئ** وهي شبكة الآسي والشقائقي وسيأتي ذكرهما إن شاء اللّه تعالى إذا أردت ذلك أدر دائرة وربّعها بخطّين ثم اعلم موضع قطب فلك البروج وأدر برجل البركار قوسًا من جهة اليمين واليسار وضع المصطرة على مطالع كلّ برج وعلّم على ذلك القوس علامة ثم ضع المصطرة على المركز ومدّ خطًّا على ذلك القوس فهو موضع البرج من المنطقة واكتب عليه اسمه وأمّا الكواكب فوضعها كالعادة وقد تقدّم ذكرها[6] وذلك من جهة البعد والمطالع واكتب على كلّ منها[7] اسمه المعلوم

وقد ترسم الكواكب في جهة البروج الموافقة لجهته وقد ترسم في الجهة المخالفة لجهة الكوكب مثل ما صوّرناه وقد ترسم الكواكب الموافقة والمخالفة في سائر البروج الموافقة بجزء ممرّه وهو أكثر كواكبًا لكن تكتب عليها جزء ممرّ الكوكب

<شكل>

D:84r البـــاب يد في معرفة وضع الأصطرلاب الآسي وهو المطبّل

ولكلّ منهما شبكة فأمّا شبكة الآسي فقد تقدّم ذكرها وقد تركّب عليه شبكة الشمالي إذا ترك فيها الكواكب الجنوبية عن مدار الجدي وأمّا شبكة المطبّل فنصوّرها في ما بعد هذه الورقة

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[3] If the ما above is to be understood as a negation, then we should add بل at this place: 'Better is not to determine it from A, but rather from B'. [4] صفيحة الأصطرلاب الشمالي المتكافئ **P**; caption om. **D** [5] Text om. **D** [6] ذكرهما **MS** [7] منهما **MS**

D:82v **P**:25r

بيان وضع الشبكة المسرطن وهو أن تدير دائرة وتربّعها بخطّين ثم تضع رجل البركار في مركز الصفيحة ورجله الأخرى على مدار الاعتدال وتنقل البركار بفتحته حتى تضعه[13] في مركز الشبكة وعلّم برجله الأخرى على أحد خطّي[14] التربيع من جهة المشرق والمغرب ثم افعل ذلك أيضًا[15] بمدار السرطان وعلّم علامة على الخطّ الآخر من جهة الشمال والجنوب وضع رجل البركار على خطّ الجنوب والشمال واجمع الثلاث علامات من جهة اليمين واليسار فهي منطقة فلك البروج ثم ضع[16] رجل البركار في مركز الصفيحة المتقدّم ذكرها والرجل الأخرى على بعد الكوكب في المقنطرات من غير أن تتعرّض إلى جهة بعده على حسب ما يراه الواضع إن شاء أن يأخذه داخلًا دائرة الاعتدال أو خارجًا عنها وانقله إلى مركز الشبكة بفتحته وعلّم برجله الأخرى على مطالع الكوكب فهو موضعه فارسمه فاكتب عليه اسمه

<**شكل**> صفة شكل شبكة المسرطن

(أسماء البروج) — <التسطيح الشمالى:> ذنب قيطس جـ (!)، غول ش، عبور جـ (!)، فخذ الدبّ ش، رامح ش، جنوبي الزبانا جـ (!)، فم الفرس جـ (!)، منكب <الفرس> ش — <التسطيح الجنوبى:> نيّر الشرطين جـ، الدبران ش (!)، الهنعة ش (!)، غميصا ش (!)، قلب الاسد ش (!)، الصرفة ش (!)، عنق الحيّة ش (!)، رأس الحوّاء ش (!)، الطائر ش (!)، متن الفرس ش (!)، كرب <الفرس> ش (!)

D:83r **P**:25v

البـــاب يجـ في معرفة وضع الأصطرلاب الشمالي المتكافئ

وهو أن تدير دائرة وتربّعها وأدر الثلاث مدارات كما تقدّم وخذ من الجدول الشمالي المستخرج من جداول الدائر بقدر الدائر لكلّ مقنطرة وعلّم على موضع ذلك[1] الدائر كلّ[2] في مداره واثبت العلامات ثم ضع رجل البركار على خطّ العلاقة ورجله الأخرى على الثلاث علامات إن اتّفق ذلك وإلّا فأبعد رجله أو قرّبها حتى تجمع الثلاث علامات المثبوتة فهي تلك المقنطرة الموافقة لذلك الدائر

[13] فضعه **D** [14] خط **P** [15] أيضًا om. **D** [16] اضع **P** [1] ذلك] تلك **P** [2] كلّ] *sic* **P**,**D**

ثم ضع[3] الكواكب كما وضعتها أوّلًا بالمطالع والبعد والجهة واكتب على كلّ كوكب منها[4] اسمه فهذه الشبكة صليب من غير دائرتها وأكثر الأصطرلابات منسوبة[5] إلى شبكته وقد تُعمل الشبكة على غير هذه الصفة لأنّ البروج تُكتب على خطّ تربيع الشبكة وهذا أحسن لأنّ مطالع البروج يُعلم من هذه المنطقة وإذا لم يكن فيها لا يمكن أن يُعلم مطالع البروج بالفلك ولا بالبلد ويُعلم منها أيضًا الطالع والغارب والمتوسّط مع يسير من التحيّل وغيرُها يعسّر فيه كما[6] ذكرناه

<شكل> شبكة الصليبي لأيّ عرض رسمت صفيحته

(أسماء البروج) — ذنب قيطس[7] ، الدبران، رجل الجوزاء، قلب الاسد، بطن الشجاع، الاعزل، فكّة، قلب العقرب، الطائر، الردف، منكب <الفرس>، فم الفرس

البـــاب يب في معرفة وضع الأصطرلاب المسرطن D:82r P:17v

وهو منسوب إلى وضع شبكته وذلك أن تدير دائرة وتربّعها وترسم مدار الاعتدال والمنقلبين وتعلّم علامات المقنطرات من الجدول المذكور أوّلًا وتجمع تلك العلامات من جهة اليمين واليسر لكن بعضها شماليًا بعضها جنوبيًا وتكون مقنطراته متكافية سمالي مركّب على شمالي وجنوب مركّب على جنوبي وتكتب عليها أعدادها وعرض الصفيحة الذي رسمت له وأمّا شبكته فنذكرها بعد هذه الورقة وتشكّلها بعد رسم الصفيحة وقد ذكر بعض[8] الفضلاء أنّ المسرطن هو جنوبي شمالي وشبكته بخلاف ما نصوّره فإنّي نظرت إلى شكل الشبكة[9] في الكتاب المعروف بالبيروني فوجدته مشكلًا بشيء من الذهاب فأثرت أن ارسم للشبكة كواكب تختصّ بها عوض عن الذهاب وسيأتي ذكرها[10] بعد هذا الباب

<شكل> صفيحة المسرطن[11]

عرض لو — مشرق، مغرب[12]

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[3] اضع **P** [4] منهما **P,D** [5] منسوبا **P** [6] ما **P,D** [7] ذنب قيطش **D** [8] ققد ذكر وبعض **P**
[9] الشبكة om. **D** [10] ذكرهما **P,D** [11] Caption om. **D** [12] Text om. **D**

الواضع إن أراد أن يضع نصفها أو[8] إن أراد أن يضع[9] كلّها

وأمّا الساعات فلا يمكن وضعها لأنّ كلّ شكل يكون آفاقي لا يمكن أن يكون فيه ساعات زمانية إلّا أن يكون معه شيء بعينه

وأمّا الشبكة لهذا الأصطرلاب فهي شبكة العادة المتقدّم ووضعها أوّل الأبواب وإنّما ينبغي أن تكتب على كلّ كوكب مع اسمه علامة جهة بعده إن كان شماليًا تكتب عليه شٓ وإن كان جنوبيًا تكتب عليه جٓ ليُعلم الكوكب الشمالي من الكوكب الجنوبي وقت العمل برسالة هذه الآلة وهو مقنطرات بلد لا عرض له ومقنطرات لعرض تسعين والله المستعان

<شكل> شكل الأصطرلاب الآفاقي وشبكته كالعادة[10]

D:81v
P:17r

البـــاب يآ في معرفة وضع الأصطرلاب الصليبي

وهو الشكل الأوّل الشمالي المذكور في أوّل الأبواب فما نحتاج أن نعيد وضعه لكنّ شبكته تشبه المصلّب فسُمّي الصليبي فنحتاج نضع شبكته ونبيّن شكلها

إذا أردت ذلك فأدر دائرة وربّعها بأربع خطوط مستقيمة ثم ضع رجل البركار في موضع قطب فلك البروج وأدر برجله الأخرى نصف دائرة تكون متّصلة بنقطتي قطب التسطيح ونصف قطر الأفق وأدر دائرة دونها تحوز أسماء البروج وضع[1] المصطرة على المركز وعلى مطالع البرج الشمالي ومدّ خطًّا بين تلك الدائرتين واكتب عليها أسماء البروج الشمالي ثم خذ فتحة بالبركار بقدر غاية ارتفاع رأس كلّ برج من الثلاثة وهي[2] الميزان وعقرب والقوس وضع رجله في مركز الشبكة والرجل الأخرى على الخطّ المار برأس السرطان من الجهة الأخرى وعلّم علامة ومدّ خطًّا يحوز بين البروج

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[8] و P,D [9] يضعها P,D [10] Caption om. D [1] اضع P [2] هما P,D

وارجع بالحمل إلى السنبلة ثم اعمل مري الأجزاء في رأس الخطّ متّصلًا بالدائرة الكبرى

وأمّا قسي الشبكة فتسمّى الأفقات في الشجّارية وينبغي أن تكون قسي الشبكة مخالفًا لقسمة قسي الصفيحة إن كانت قسي الصفيحة ستّة ستّة فينبغي أن تكون قسي ⌈ هذه الشبكة عشرة عشرة حتى تُظهَر قسي الصفيحة بين قسي الشبكة وذلك على قدر رأي الواضع وتكون قسي ⌉[4] مخرّقة إن كانت نحاس أو خشب أو غير ذلك وقد يستغني عن الشبكة بخيط أو بعضادة وأحسنها الشبكة فهي أصل الشجّارية[5] فإنّها آفاقية

<شكل> شبكة الشجّارية[6]

(أسماء البروج) — <التسطيح الشمالي:> ردف، طائر، واقع، حوّاء، عنق الحيّة[7] ، منكب العوّاء، الرامح — <التسطيح الجنوبي:> جنوبي الزبانا، فرس، فم الحوت

البـــاب يَ في معرفة وضع الأصطرلاب الآفاقي المستنبط بأرض بكّة شرّفها الله تعالى في سنة المجاورة بها سنة ثلاث وعشرون (!) وسبعمائة **D**:81r **P**:15v

فلمّا وصلت إلى مصر وجدته مرسومًا في نحاس بوضع بلاد المغرب منسوبًا إلى الشيخ الفاضل ابراهيم بن علي بن باص الأندلسي فعرفت أنّه سبقني بذلك فاختبرته في وضعه ورسالته فوجدته موافقًا للخير والخبر

فإذا أردت ذلك فأدر دائرة وربّعها واقسم تلك الدائرة شسَ قسمًا وهي دائرة الحجرة ثم أدر الثلاث مدارات كما تقدّم ثم ضع مقنطرات كما وضعت مقنطرات الشجّارية لكنّ مدار الاعتدال في الشجّارية هو الدائرة الكبرى وهنا هو الدائرة الوسطى والسموت كما وضعتها أولًا وإنّما نقطة سمت الرأس هنا على دائرة الاعتدال وقد يستغني بالنصف من هذا الشكل عن كلّه على قدر ما يراه

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[4] ⌈…⌉ om. **D** [5] للشجارية **P** [6] الشّجاذِيّة **D**; In **D** the illustrations of Chapters 9[2] and 10 have been interchanged. Two notices in the margins of folios 80v and 81r warn the reader:

هذا هو الأسطرلاب الآفاقي وموضعه في الصفحة اليسرى وصفة وضعه مذكور أعلاه وإنّما وُضِع هنا سهوًا

and

هذه منطقة الكواكب وموضعها الصفحة اليمنى وصفة وضعها مذكور أعلاها وإنّما جُعِلت هنا سهوًا

[7] عنق الحيّة **D** om.

وأمّا وضع الشبكة أن تدير دائرة بقدر دائرة الاولى وتربّعها وتضع نصفها قسي كما وضعت السموت والمقنطرات ونصفها الآخر على حالته ويكون مري الأجزاء في طرف الخطّ المارّ بالمركز المقاطع لخطّ القسي وهذا الشكل هو الشكّازية بعينها

فإنّ المقنطرات في هذا الأصطرلاب هي المدارات في الشكّازية وأمّا السموت هي الممرّات وليس لشكّازية شبكة وإنّما عُمِل لها أفق مائل أو خيط فما نحتاج أن نشكّلها في موضع آخر فيستغني هذا الشكل عن شكلها وليس فيها زائدًا إلّا خطّ الطول وهو الذي يكون عليها أسماء البروج مرسومًا على الميل الاعظم

<شكل>

D:80v P:15r **بيان وضع منطقة الكواكب في شبكة الشجّارية** وذلك أن تضع رجل البركار في مركز الصفيحة والاخرى في المقنطرات على قدر بعد الكواكب وانقله بفتحته حتى تضع رجله في مركز الشبكة والرجل الاخرى حيث وقعت على خطّ مطالع توسّطه وينبغي أن يكون مطالع الكوكب اقلّ من ص أو أكثر من ر ع إن كان بعده جنوبيًا او شماليًا وكلّ كوكب تكتب عليه اسمه وجهة بعده

وأمّا منطقة البروج فهو[2] أن تضع رجل البركار في مركز الصفيحة والأخرى على قدر الميل الاعظم وانقل حتى تضع رجله في مركز الشبكة والرجل الأخرى حيث وقعت على الخطّ المارّ فوق المركز وعلّم علامة ثم افتح البركار وضع رجله على تلك العلامة ورجله الاخرى على الخطّ المارّ تحت المركز وانقل رجله التي في العلامة إلى نقطتي تقاطع الدائرة للخطّ الآخر المارّ بالمركز فإن اتّفق ذلك فأدر قوسًا فهو المنطقة فإن لم توافق فتقدّم أو تأخّر حتى توافق ذلك ثم أدر دائرة أخرى لتحوز البروج ثم ضع المصطرة على مقاطع الجدي وعلى المركز ومدّ خطًّا بين الدائرتين وكذلك تفعل بالدلو والقوس والعقرب فقد كُمِلت البروج فاكتب أسمائها[3] بين تلك الدائرتين مبتدئاً من الميزان إلى الحوت

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[2] فهو] هو P,D [3] أسمائهم P,D

لأحد المنقلبين والاعتدال ثم اجمع تلك العلامات فهي[11] قسي المقنطرات وافعل كما فعلت أوّلًا

فإن أردت السموت فارسمها كما رسمت أوّلًا وتركها أولى من رسمها فإنّه يُظلم وتدخل قوس في قوس فيشتبه ذلك على من أراد أن يعلم منه السمت وأحسن ما يُعلَم السمت من هذا الشكل <هو> من دائرة الحجرة وسيأتي ذكره في جملة أبواب رسالة أصطرلاب الراغب المستغني عن الشكل الغائب وكذلك الساعات لا ينبغي أن تُرسم فيه فإنّ كلّ ربع مخالفًا (!) للآخر فإنّ ساعاته تُعلَم من دائرة الحجرة أيضًا

وأمّا الشبكة فوضعها كما تقدّم أوّلًا وإنّما يكون البرج ونظيره في موضع البرج لمنطقة واحدة أعني تكون كتابة أسماء البروج الاثنا عشر مستقيم وراجعًا وأحسنها أن تكون منطقتين

<شكل>

الباب ط̅ في معرفة وضع الأصطرلاب الرومي المعروف بالشجّارية[1] D:80r

وهو أن تدير دائرة وتربّعها ونستخرج له جدولًا من الجداول المتقدّمة ويكون ذلك لبلد لا عرض له لرأس الاعتدال فوجدناه الارتفاع موافقًا للدائر فتركنا جدوله بسببه ثم وضعنا المصطرة على قطب التسطيح وعلى عدد المقنطرة ونعلّم على تقاطع المصطرة لخطّ العلاقة ونعلّم علامة ونحفظها ثم نضع رجل البركار على خطّ نقطتي الشمال والجنوب وأدرنا برجله الأخرى نصف دائرة على قسمة الدائرة العظمى وهي مدار الحمل ولا نزال نفعل ذلك حتى نكمّل المقنطرات

وأمّا السموت فضع رجل البركار على خطّ وسط الدائرة المقاطع لخطّ نقطتي الشمال والجنوب وأدر برجله الأخرى قوسًا من نقطتي الشمال والجنوب حتى تكمل قسي السموت

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[11] فهما MS [1] The original word الشجّارية seems to have been corrected into الشكّازية in **MS**

فإن أردت المقنطرات فخذ من الجدول ما بحيال تلك المقنطرة من فضل الدائر وخذ بمثله من قسمة قوس الربع مبتدئاً من خطّ الزوال ثم ضع المصطرة على انتهاء العدد في قوس الربع وعلّم على المدار المطلوب من أحد الثلاثة وهي[5] الحمل والسرطان والجدي فإذا كملت علامات الثلاث مدارات فاجمعها[6] قوسًا وكلّ قوس منها[7] نصف دائرة فإذا تكمّلت علامات الحمل فاعمل ذلك للثور والجوزاء حتى تجمع علامات الثلاث مدارات إلى أن تتكمّل المقنطرات

فإن أردت السموت فاستخرج نصف قطر دائرة أوّل السموت كما تقدّم وبعدها كد ك وخذ فتحة بالبركار وضع رجله في نقطة سمت الرأس والرجل الأخرى حيث وقعت على خطّ وتد الأرض فاثبتها وأدر برجله قوسًا من سمت الرأس إلى الأفق ثم خذ فتحة بقدر الدائر الموافق لسمت عشرة عشرة الذي في الجدول وضعه على تلك المدار من أحد الثلاثة لجميع العلامات إلى أن تتكمّل[8] السموت

فإن أردت الساعات فاقسم كلّ مدار من الثلاثة بستّة أقسام واجمع العلامات واجعلها نقطًا[9] حتى لا تختلط بالسموت فإنّ الساعات في هذين الربعين تكون فوق المقنطرات

وأمّا وضع الجنوبي فهو كما وضعت الشمالي وإنّما أفقه فوق مركزه وكلّ منها له جدول لوضع المقنطرات

<شكل>

البـــاب ح في معرفة وضع الأصطرلاب اللّولبي D:79v

وهو أن تدير دائرة وربّعها وأدر دائرة الجدي والسرطان والحمل كما تقدّم ثم خذ فتحة بالبركار بقدر فضل الدائر الذي[10] في الجدول وضع رجله في تقاطع أحد الخطّين لتلك الدائرة والرجل الأخرى حيث وقعت على الدائرة فضع المصطرة عليه وعلى المركز وعلّم على تقاطع جنب المصطرة لتلك الدائرة

[5] MS وهما [6] MS فاجمعهما [7] MS منهما [8] MS تكمل [9] MS نقط [10] MS التي

من تلك القسمة ثم وضعنا رجل البركار في أحد طرفي الأفق والرجل الاخرى حيث وقعت على الخطّ فهو مركز الأفق فاثبته وأدر برجله الأخرى دائرة كاملة فهي دائرة الأفق ثم ربّع الدائرة لخطّ آخر فهو خطّ الاستواء فضع رجل البركار في المركز والرجل الأخرى على تقاطع الأفق لخطّ الاستواء فأدر برجله دائرة فهي دائرة الاعتدال فافعل من الجدول المكتوب عليه المقنطرات الجنوبية وإذا كملت الثلاث مدارات وعلامات المصطرة فاجمعها[2] إلى أن تكمل المقنطرات ثم ضع السموت كما وضعت الشمالي ومجموعها[3] على نقطة سمت الرأس

<شكل>

D:79r البـــاب ز في معرفة وضع أرباع الأصطرلاب الكامل

وأمّا الشمالي وهو أن تدير قوسًا وتربّعه بخطّين وهما خطّ المشرق وخطّ الزوال ثم تقسم أحد الخطّين بقدر نصف قطر الأفق الأبعد وهو س لب دقيقة لعرض لو وخذ من تلك القسمة بقدر نصف القطر الأقرب وهو و كد دقيقة وضع رجل البركار في مركز الربع والرجل الأخرى حيث وقعت تحت الخطّ المقسوم فهو موضع الأفق الأقرب إلى القطب ثم اجمع أنصاف الأقطار المذكورة فهي[4] سو نو ثم خذ نصف ذلك وهو لج كح دقيقة بفتحة بالبركار من تلك القسمة وضع رجل البركار في أحد طرفي الأفق والرجل الاخرى حيث وقعت على الخطّ المقسوم فهو مركز الأفق فاثبت رجله وأدر برجله الاخرة نصف دائرة فهو قوس الأفق ثم ضع رجله في المركز والاخرى في موضع تقاطع أحد الخطّين لقوس الأفق وأدر نصف دائرة كاملة فهو مدار الحمل والميزان ثم خذ فتحة من تلك القسمة بقدر نصف قطر مدار السرطان وهو يب ند دقيقة <وأدر نصف دائرة فهو مدار السرطان ثم خذ فتحة بقدر نصف قطر مدار الجدي وهو س > وأدر قوسًا من الأفق إلى خطّ الزوال فهو مدار الجدي

[2] فاجمعهما MS [3] ومجموعهما MS [4] فهما MS

وأردنا أن نضعه لعرض لو فاستخرجنا نصف قطر الأفق الأقرب فوجدناه و كد ووجدنا الأبعد س لب <و>قسمنا نصف قطر الدائرة الكبرى بقدر الأبعد وهو س لب وأخذنا من هذه القسمة إلى جهة الوتد بقدر و كد ثم جمعنا س لب دقيقة و كد فكان مجموعهما سو نو دقيقة أخذنا نصفها فكان لجكح دقيقة وهو مركز الأفق فإن شئت أن تقسم من نصف القطر الأقرب إلى نصف قطر الأبعد بنصفين فهو مركز دائرة الأفق وإن شئت فخذ فتحة بالبركار بقدر نصف مجموع ذلك وهو لجكح دقيقة وضع رجله في أحد طرفي الأفق والرجل الاخرى حيث وقعت على الخطّ فهو مركز الأفق فأدر برجله دائرة كاملة فهي دائرة الأفق ثم ربّع الدائرة لخطّ اخر وهو خطّ الاستواء فضع رجله في المركز والأخرى على تقاطع الأفق لخطّ[9] الاستواء وأدر[10] دائرة وهي للحمل ثم افعل كما فعلت أولًا وشبكته كما تقدّم وإنّما يكون بقدر الدائرة الكبرى والله أعلم

<شكل> صفيحة الأصطرلاب[11] الشمالي الكامل

عرض لو — مشرق، مغرب

الباب و في معرفة وضع الأصطرلاب الجنوبي سُمّي الكامل لكون أنّ مقنطراته كاملة من نقطة الشمال إلى نقطة الجنوب D:78v

وهو أن تدير دائرة وضع المصطرة على المركز وخطّ خطًّا مستقيمًا متّصلًا بطرفي تلك الدائرة ثم اعلم نصف قطر الأفق الأقرب والأبعد كما ذكرناه في ظهر هذه الورقة ثم اقسم نصف قطر هذه الدائرة بقدر نصف قطر الأفق[1] الأبعد وهو س لب وخذ من هذه القسمة بقدر نصف قطر الأفق الأقرب وهو و كد دقيقة وضع رجل البركار في مركز هذه الدائرة الكبرى واضرب برجله الأخرى إلى جهة العلاقة فهو موضع الأفق الأقرب إلى القطب ثم اجمع أنصاف الأقطار المذكورة فكان مجموعهما سو نو أخذنا نصفها فكان لجكح دقيقة

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[9] لخط (marked صح) marg. **D**. A sign here in **P** indicates that the text continues in the lower margin, but it is not found, as the lower margin was probably cut off. [10] وادر لتّان (؟) written underneath وادر **D** [11] الأسطرلاب **D** [1] الأفق] الأفق الأفق **MS**

<شكل>

لعرض لو̅ شمال — [هذا الربع بخيطين والاوّل منهما][15] في المركز والآخر في سمت الرأس[16]

<شكل>

لعرض لو̅ شمال — هذا الربع بخيطٍ واحدٍ في المركز

البـــاب ه̅ في معرفة وضع الأصطرلاب الشمالي[1] الكامل لكون أنّ مقنطراته كاملة من نقطة الجنوب إلى نقطة الشمال

D:78r
P:14v

وهو أن تدير دائرة كما تقدّم ثم تضع المصطرة على المركز وتمدّه خطًّا إلى طرفي الدائرة ثم اعلم نصف قطر الأفق إلى القطب كما ذكرناه أوّلًا ونثبت (؟) أيضًا وذلك أن نأخذ ظلّ نصف عرض البلد من الجدول منكوسًا[2] وزد عليه ثلثيه فما اجتمع انقص منه لكلّ درجةٍ دقيقة فما بقي فهو المطلوب واحفظه[3]

ثم اعلم نصف قطر الأفق الأبعد وهو أن تأخذ ظلّ نصف عرض البلد مبسوطًا وزد عليه ثلثيه فما اجتمع انقص منه لكلّ درجة دقيقة فما بقي فهو نصف قطر الأفق الأبعد فزد عليه المحفوظ وخذ نصف مجموعهما فما كان اقسم نصف قطر[4] الدائرة بقدره ثم خذ من تلك القسمة بقدر المحفوظ الأوّل مبتدئاً من تقاطع الدائرة على ذلك الخطّ فهو مركز دائرة الحجرة ⌈ فضع[5] رجله في المركز والأخرى على طرف الدائرة الأبعد وأدر دائرة كاملة فهي الحجرة ⌉[6] فاقسمها ش̅س̅ قسمًا متساويًا ومدّ خطّ الاستواء ثم ضع[7] رجل البركار في المركز والرجل الأخرى على تقاطع خطّ الاستواء[8] لخطّ الدائرة الأولى التي هي دائرة الأفق وأدر دائرة فهي دائرة الاعتدال ثم أدر مدار المنقلبين كما تقدّم ثم ضع المقنطرات من الجدول وكذلك السموت والساعات والشبكة ومنطقة البروج والكواكب ولا يحتاج إلى مقنطرات الانحطاط

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[15] [...] upper margin cut off in **P**; om. **D**   [16] في المركز والآخر في سمت الرأس om. **D**   [1] الشمالي above the line **P**   [2] منكوس **P**,**D**   [3] و om. **P**,**D**   [4] قطر marg. **P**   [5] فاضع **P**   [6] ⌈...⌉ marg. **P**   [7] اضع **P**   [8] ثم ضع ... خطّ الاستواء crossed out and then rewritten **P**

جدول لوضع الربع المسمّت لعرض لوَ شمال											
عدد	سرطان			عدد	حمل			عدد	جدي		
الدائر	ارتفاع	سمت	ارتفاع	الدائر	ارتفاع	سمت	ارتفاع	الدائر	ارتفاع	سمت	ارتفاع
و	د يز	ي	ند ن	و	د نا	ذ	ذ ذ	و	ه ط!	ل	ذ ذ
يب	ح مد	ك	سو	يب	طلح	ي	يجلو	يب	ح يو	م	ي ذ
يح	يد يج	ل	ع	يح	يد ل	ك	كه كا	يح	يا كط	ن	يح ذ
كد	يز ند	م	عب	كد	يط يه	ل	لد له	كد	يه ح	س	كجذ
ل	كب لج	ن	عجل	ل	كج نب	م	ما لا	ل	يح لد	ع	كز ذ
لو	كزك	س	عه	لو	كح كه	ن	موكح	لو	كا لا	ف	ل ذ
مب	لب ح	ع	عو	مب	لب مه	س	ن ح	مب	كد ب	ص	ل كه
مح	لز ذ	ف	عز	مح	لو نز	ع	نب يد	مح	كو كز		
ند	ما ن	ص	عز ل	ند	م ند	ف	نجكو	ند	كح يب		
س	مو م	شمال		س	مدكح	ص	ند ذ	س	كط ك		
سو	نا ل	ي	ي ل	سو	مزلز			سو	ل ذ		
عب	نو يب	ك	ك يز	عب	ن يز			عا لط	ل كه	سمت جنوب	غاية
عح	س ند	ل	ل ذ	عح	نب ك	حوت				ي	مو
فد	سه لب			فد	نجل	دائر	ارتفاع			ك	لح
ص	سط ن	جوزاء		ص	ند ذ	عح	ما ذ			سمت شمال	غاية
صو	عجما	دائر	ارتفاع			ثور				ي	سب
قب	عو يد	قب	عجذ			دائر	ارتفاع			ك	ع
قح	عزذ					صو	سد				
قح كا	عزله										

هذا الجدول مستخرج من جداول الدائر

D:96v P:14r [13] وهذين[14] الربعين وضعهما الشيخ محمّد بن السائح في ربع من نحاس الوجه الواحد بعضادة عليها مقنطرات الارتفاع منقوشة مثل عضادة المساترة مركزها القطب والوجه الآخر بعضادة عليها مقنطرات الارتفاع منقوشة مثل الأفق المائل في الشكّازية مركزها سمت الرأس وقد ابتاع بعد وفاته رحمة اللّه عليه

[13] The text on this page is written upside-down in **P** [14] وهذا **P**,**D**

المركز قوسًا من مدار الجدي إلى مدار السرطان وحقق قوس الأفق ثم ضع رجل البركار في أوّل عدد القوس ورجله الأخرى على قدر الارتفاع لذلك الدائر للمدارات الثلاثة[1] التي في الجدول إن أردت خمسة أو ثلاثة ثلاثة[2] أو غير ذلك واضرب برجله على المدار الأكبر والأصغر والأوسط فإذا علّمت على هذه الثلاث[3] مدارات فهي علامات قسي الدائر فإن تكمّل أحد المنقلبين فاجمع بين علامات الاعتدال وعلامات المنقلب الآخر فإن تكمّل الاعتدال فاستخرج للبرج[4] الذي بينهما ولا تزال تفعل ذلك حتى تُكمّل قسي الدائر

فإن أردت السمت لرأس المنقلبين فاستخرج لذلك السمت ارتفاعًا للبرجين المذكورين[5] وافعل كما فعلت بالدائر واعلم أنّ جدول الحمل محسوب في الجدول المقدّم ذكره[6] فإذا علّمت على الثلاث مدارات فاجمعها[7] قوسًا فهي[8] قسي السموت فإن تكمّل أحد المنقلبين فاجمع علامات الاعتدال وعلامات المنقلب الآخر فإن كُمِل مدار الاعتدال فاستخرج للبرج الذي بينهما ولا تزال تفعل ذلك حتى تُكمَّل قسي السموت

فقد وضعت هذا الربع المستنبط ليستغني به عن ربع المقنطرات المتقدّم ذكره وقد اشترطنا في رسالته أن يُعلَم منه جميع ما يعلم في ربع مقنطرات العادة إن شئت بخيط أو بعضادة وقد سمّيتها « السكّر المنبّت بالعمل بالربع المسمّت » وعدّة أبوابها مائة[9] وهي كفاءة[10] ولو لا ملّ قارئها[11] لجعلناها[12] خمسمائة وحسبنا الله ونعم الوكيل

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[1] الثلثة **D** [2] ثلاثة] ثلا **D** [3] ثلث **D** [4] واستخرج البرج **P,D** [5] للبرجين المذكورة **P,D** [6] ذكره om. **P** [7] فاجمعهما **P,D** [8] فهما **P,D** [9] مائا **P** [10] كفاءا **P** [11] ملّل قارها **P,D** [12] لجعلنها **P**; لجعلتها **D**

D:99r
P:16r

البـــاب جَ في معرفة وضع الأرباع المنسوبة إلى جهة الأصطرلابات[2] المتقدّم ذكرها[3]

وذلك أن تدير قوسًا وتربّعه ثم خذ فتحة بقدر تفاضل[4] الدائر للأفق المكتوب في الجدول الذي وضعت به المقنطرات[5] وضع رجله على خطّ الزوال المقاطع للدائرة الكبرى وعلّم برجله الأخرى في قوس تلك الدائرة وافعل كذلك إلى أن يتهي فضل الدائر تفعل كذلك في الثلاث[6] مدارات ثم تجمعها[7] قسيًا[8] فهي[9] المقنطرات

ثم خذ فتحة بقدر ما[10] بحيال جدول السمت من بعد مركز دائرة أوّل السموت[11] ⌉ وضع رجل البركار في قطب التسطيح ورجله الأخرى حيث وقعت على خطّ الوتد ⌈[12] ومدّه خطًّا مستقيمًا فهو خطّ مشرق دائرة أوّل السموت واجمعها[13] على نقطة سمت الرأس كما تقدّم

<شكل> شكل الأرباع لعرض لوَ شمال

الربع الجنوبي — أفق عرض لوَ شمال[14]

الربع الشمالي — أفق عرض لوَ شمال[15] — الفضلة يح ل[16]

D:96r
P:16v

البـــاب دَ في معرفة وضع الربع المسمّى الشُكّر المنبَّت عرف بالمسمّت

إذا أردت ذلك أدر قوسًا وربّعه واقسمه صَ قسمًا ثم اقسم خطّ المشرق صَ قسمًا متساويًا وابدأ من المركز ثم ضع رجل البركار في المركز ورجله الأخرى على غاية الارتفاع وأدر قوسًا من خطّ المشرق إلى خطّ نصف النهار إلى أن تكمل المدارات واكتب على كلّ مدار اسم برجه يمينًا ويسارًا ثم ضع رجله في المركز ورجله الأخرى في أوّل عدد قوس الربع واثبتها واضرب برجله التي في

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[2] الأسطرلابات D [3] ذكرهما P,D; in fact we would rather expect الاصطرلابين المتقدم ذكرهما since two astrolabes, the northern and the southern, have been presented until now. [4] تفاضل P [5] وضعت به في المقنطرات D [6] الثلث D [7] تجمعهما P,D [8] قسي P,D [9] فهما P,D [10] ما above the line P [11] من بعد مركز دائرة أول السموت marg. P [12] ⌈…⌉ om. D [13] واجمعهما D; فاجمعهما P [14] أفق عرض لوَ شمال om. P [15] أفق عرض لوَ شمال om. P [16] الفضلة يح ل om. P

الكوكب فاشبكه لأقرب موضع في الشبكة وارسم عليه اسمه فإن كانت فيها[20] مقنطرات الانحطاط وكانت دائرة الجدي الكبرى فاكتب على الكواكب الجنوبية عن مدار الجدي مع اسمه جـ وإن كانت الصغرى فاكتب عليه ش ليُعلَم من ذلك جهته لأنّ مقنطرات الانحطاط رسمناها[21] بسبب هذه الكواكب المكتوب عليها هذه الأحرف ثم <اعمل> مري الأجزاء في رأس البروج الأقرب من دائرة الحجرة فإن أردت وضع الساعات بالهندسة فاقسم كلّ مدار يب قسمًا واجمعها[22] قوسًا فقد وضعتها

<شكل> شكل الأصطرلاب الشمال لعرض لو شمال[23] عرض لو ساعاته يد ل[24] D:98v P:26v

<شكل> شبكة الشمالي لأنّ الجدي أكبر الدوائر

(أسماء البروج)[25] — ذنب الحوت، دبران، رجل الجوزاء، عبور، غميصا، قلب الاسد، رامح، فكّة، قلب العقرب، رأس الحوّاء، واقع، طائر، ردف، فم فرس[26]

الباب ب في معرفة وضع مقنطرات الانحطاط بانفرادها وهي مقنطرات الاسطرلاب الجنوبي الشمالي D:98v

فإنّه منسوب إلى وضع منطقة الشبكة إن كان الجدي أكبر الدوائر في الشبكة فهو جنوبي وإن كان أصغرها فهو شمالي فإذا أردت ذلك فافعل ما ذكرناه في الباب الأوّل في الوضع وخذ من الجدول لمقنطرات الانحطاط واعمل كما تقدّم يحصل المطلوب

<شكل> شكل الأسطرلاب الجنوبي

عرض لو ساعاته يد ل[1] — مشرق، مغرب ـ أولة، ثانية، ... ، ثانية عشر

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[20] فيه **D** [21] رسمناهم **P,D** [22] واجمعهما **P,D** [23] The two figures (plate and rete) are illustrated twice in **D**, first on f. 97v and then on f. 98r. The first one is in the (here neglected) handwriting of copyist C1, and is incomplete and incorrect, whilst the second one reveals the neat handwriting and drawing of copyist C3. [24] عرض لو ساعاته يد ل om. **P** [25] In the edition of the text on the illustrations we shall denote by (أسما البروج) all occurrences of the names of the zodiacal signs, namely حمل, ثور, جوزاء, سرطان, أسد, سنبلة, ميزان, عقرب, قوس, جدي, دلو, حوت (always written without the article *al-*). [26] فم الحوت (?) **D** [1] عرض لو ساعاته يد ل om. **P**

على مركزها موازيًا لخطّ القطب ويسمّى خطّ مشرق دائرة أوّل السموت يمينًا ويسارًا ثم ضع رجل البركار على ذلك الخطّ ورجله الأخرى على نقطة سمت الرأس وعلى كلّ علامة من مدار الحمل المحتفظ بها[13] إن اتّفقا (؟) وأدر قوسًا من المدار الأكبر إلى الأفق ومن المدار الأكبر أيضًا من جهة اليمين واليسار إلى أن تكمل السموت

فإن أردت الساعات فاجعل المصطرة على أجزاء ساعات ذلك المدار و <على> قطب الدائرة وعلّم على كلّ مدار من الثلاثة واجمعها[14] بالتقارب والتباعد إلى أن تكمل اثنى عشر ساعة زمانية أو ساعاتها[15] المستوية

فإن أردت مقنطرة الانحطاط فضع من الجدول الذي في ظهر هذه الورقة على المدار المذكور لذلك البرج وافعل كما فعلت أوّلًا فإذا وضعتها[16] وجب عليك أن تكمل السموت فوق المقنطرات وأسفلها فقد كملت وضع الصفيحة

فإن أردت وضع الشبكة فخذ فتحة بقدر نصف قطر الدائرة الكبرى وأدر دائرة وربّعها ثم خذ بقدر ما بين المدار الأكبر والأصغر من فوق المقنطرات وأسفلها وضع رجل البركار في موضع تقاطع الدائرة الكبرى لخطّ التربيع واضرب برجله الأخرى على الخطّ المذكور فاثبت هذه الرجل وأدر برجله الأخرى دائرة فهي منطقة فلك البروج فأدر تحت تلك الدائرة ثلاث دوائر الدائرة الأولى تكتب عليها أسماء البروج و <على> الأخرى أجزاء بها[17] فإذا فعلت ذلك ضع المصطرة على مطالع ذلك البرج المستخرج من الجدول وعلى مركز الشبكة ومدّه خطًّا على تلك الثلاث دوائر إلى أن تكمل سائر البروج

فإن أردت الكوكب فضع المصطرة على مطالع توسّطه وعلى مركز الشبكة ومدّ خطًّا متّصلًا بالمركز ثم ضع رجل البركار في مركز || الصفيحة ورجله P:26r
الأخرى[18] على مقنطرة غاية ارتفاعه وانقل البركار حتى تضع رجله في مركز الشبكة || ورجله الأخرى حيث وقعت على ذلك الخط فهو موضع مري[19] D:97v

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[13] بهما MS [14] واجمعهما MS [15] ساعاتهما MS [16] وضعتهما MS [17] بهما MS [18] الأخرى om. D [19] مرى D

البـــاب اَ في معرفة وضع مقنطرات الأصطرلاب الشمالي الجنوبي فإنّه منسوب إلى وضع منطقة الشبكة إن كان الجدي أكبر دوائر الشبكة فهو شمالي وإن كان أصغرها فهو جنوبي D:97r

فأدر دائرة واقسمها شس قسمًا متساويًا وربّعها واقسمه ل قسمًا وخذ من تلك القسمة يط لط دقيقة وأدر بتلك الفتحة فهي دائرة الحمل ثم خذ من تلك الفتحة يب ند دقيقة وأدر دائرة فهي دائرة السرطان ثم خذ يه ل للثور ثم خذ يج مب دقيقة للجوزاء وأدرهما وهيّئها[8] لوقت الحاجة إليه ثم خذ لسمت الرأس ي ب ثم خذ للكوكب الذي بعده ل للقطب الأقرب ح مو وللأبعد يا مو كلّا منهما على خط الزوال في البسط الشمالي والأولى هي دائرة الجدي وبالعكس في البسط الجنوبي فإن أردنا أن نقيم الدليل على كيف نعمله من الجداول المتقدّمة وتسمّى معرفة أنصاف أقطار المدارات والمقنطرات فنستخرجه من الفصل المذكور في آخر الأبواب ونجعله جدولًا فإن شئنا أن نضع به فلا يحتاج إلى جدول آخر وإن شئنا أن نفعل ما ذكرناه

فإذا أردت <المقنطرات>[9] ضع المصطرة على كلّ مدار منها وهي[10] الحمل والسرطان والجدي المحسوب له فضل الدائر فإذا انتهت غاية الحمل فكمّل المقنطرات بالثور فإذا انتهت غاية الثور فكمّلها[11] بالجوزاء فإذا انتهت غاية الجوزاء فبالكوكبين المذكورة إلى أن تصل إلى نقطة سمت الرأس

فإن أردت السموت فخذ ما بحيال السمت من الدائر وافعل كما فعلت بالمقنطرات لكن تبداء من خطّ المشرق والمغرب وتعلّم على تقاطع المصطرة لمدار الحمل وتحتفظ بها[12] ثم تضع رجل البركار على خطّ الوتد وتتقدّم أو تتأخّر حتى تجمع قطبي التسطيح ونقطة سمت الرأس فأدر برجله الأخرى دائرة وهي دائرة أوّل السموت هذه طريق الهندسة وإن شئت بطريق الجدول فاستخرجه من الفصل المذكور في آخر الأبواب فإذا أدرت دائرة أوّل السموت فأقم خطًّا

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[8] وهيها MS   [9] المقنطرات] هذه الثلاث مدارات MS   [10] منهما وهما MS   [11] فكملهما MS
[12] بهما MS

جدول لوضع المقنطرات لعرض لو شمال									
عدد المقنطرات	سرطان فضل الدائر		عدد المقنطرات	حمل فضل الدائر		عدد المقنطرات	جدي فضل الدائر		
	جـ	ق		جـ	ق		جـ	ق	
أفق	قح	كا	أفق	ص	ذ	أفق	عا	لط	
و	ق	ك	و	فب	لو	و	سب	ن	
يب	صب	ذ	يب	عه	ز	يب	نب	مز	
يح	فد	ي	يح	سز	له	يح	مب	نا	
كد	عو	لد	كد	نط	مط	كد	ل	ذ	
ل	سط	ح	ل	نا	نا	ل	ز	ك	
لو	سا	لو	لو	مجـ	كو	ذ	ذ	ذ	
مب	ند	ه	مب	لد	يه				
مح	مو	لح	مح	كجـ	يو	عدد	حمل		
ند	لط	ح	ند	ذ	ذ	السمت	ارتفاع		دائر
				ثور		ي	يجـ	لو	يو نجـ
س	لا	لو	س	يح	لو	ك	كه	كا	لا نح
				جوزاء		ل	لد	له	مد لد
سو	كجـ	ن	سو	كا	لد	م	ما	لا	نه ذ
عب	يد	نز	عب	يا	كجـ	ن	مو	كح	سجـ لط
	كوكب بعده شمال لو			كوكب بعده شمال ل		س	ن	ح	عا لز
عح	يد	ن	عح	يب	كب	ع	نب	يد	عز نا
فد	ز	كو	فد	ذ	ذ	ف	نجـ	كو	فد ذ
ص	ذ	ذ	ذ	ذ	ذ	ص	ند	ذ	ص ذ

للحمل وأثبته بحيال عدد السمت ثم استخرجنا الدائر من الارتفاع والسمت وأثبتناه بحيال عدد السمت أيضًا وهو المختاج إليه لوضع السموت وإن شئت فاستخرج الارتفاع لذلك السمت لرأس الاعتدالين كما ذكرناه أو تدخل بالسمت في أنصاف الفضلات للعرض المطلوب وخذ ما بحياله من البعد فهو الارتفاع لذلك السمت لرأس الاعتدالين خاصّة يحصل له الدائر[4] من بابه واثبته في الجدول وهو الذي أثبتناه

وأمّا المدارات فاعلم غاية تلك الدرجة من الباب دَ وافهمه وأمّا قسمة المنطقة فاعلم مطالع كلّ برج من جدول المطالع بالفلك واحفظه لوقت الحاجة إليه

الجدول الآخر لوضع الساعات للرخامات المبسوطة والقائمات والمائلات والمخروطات والمقبّبات واصطوانات وغير ذلك من الرخامات المخصوصة بالظلّ المبسوط أو المنكوس أو المستعمل أو المائل على سطح الرخامة وغيرها فاستخرجنا ظلّ كلّ ساعة وسمتها من قبل ارتفاعها من الأبواب المذكورة وأثبتناه تحت كلّ برج من المنقلبين لأيّ عرض أردنا وهو جدول البسيطة ||

إن أردنا ساعة زمانية أو مستوية وقد صوّرناهما جدولين زمانيًا ومستويًا **D**:27r
وإن أردنا أن نضع الدائر فقد استخرجنا له جدولًا مركّبًا[5] على الدائر ثلاثة ثلاثة[6] لعرض لوَ وعرفنا الارتفاع ذلك الدائر من بابه وأثبتناه في الجدول ثم عرفنا الظلّ المبسوط والمنكوس والسمت لذلك الارتفاع كلّ من بابه وأثبتناه في الجدول لوقت الحاجة إليه فإن أردنا ارتفاع في البسيطة فيحتاج أن نخرج له جدولًا مركّبًا[7] على ارتفاع خمسة أو ستّة وعرفنا ظلّ ذلك الارتفاع مبسوط ومنكوس من بابهما (؟) وأثبتنا كلّا منهما لوقت الحاجة إليه والحمد للّه وحده

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[4] دائر **MS** [5] مركب **MS** [6] ثلثة ثلثة **MS** [7] مركب **MS**

القسم الثاني في الآلات الفلكية

قـــال الشيخ الإمام العالم العلامة وحيد دهره وفريد عصره مصنّف هذا الكتاب رضي اللّه عنه فمن أراد أن يستخرج عملًا من الأعمال فيطلبه من بابه ويفعل ما ذكرناه فإن أراد أن يستمحنه فعليه بالأعداد المتناسبة المجدولة في ظهر هذه الورقة فإن لم تجده فيه فاعلم أنّه مشروح مبيّن من بابه لا يحتاج ضرب ولا قسمة ولا جذر ولا نسبة واعلم أنّ جميع ما تطلبه من ثمرة هذا الفنّ فهو موجود فيه لا خلا[1] من أصول بعض الأبواب فإنّها ليست بموجودة لأنّ إذا حضر الـ ... (؟)[2] اليتيم فإنّ جميع الأبواب موجودة فلا يحتاج إلى الموصّل إليها مثل حصّة السمت وجيب الترتيب والقطر وما أشبه ذلك وقد يُعلَم السمت من قبل الارتفاع من غير حصّة وقد يُعلَم الدائر من قبل الارتفاع من غير جيب الترتيب وأمّا الارتفاع من الظلّ فلا بدّ له من القطر فالقطر هو أصل الارتفاع فإذا أخرجنا الارتفاع من الظلّ من غير قطر فلا نحتاج إلى قطره وما المقصود لكلّ شيء إلّا ثمرته واللّه سبحانه المستعان D:26v

وقد استخرجنا جدولين أحدهما[3] لوضع المقنطرات والسموت لسائر الآلات المخصوصة بذلك فإن شئنا أن تكون سدسًا أو ثلثًا وغير ذلك فاستخرجنا الدائر لقدر عدد المقنطرات من الباب $\overline{\text{كا}}$ واسقطه من نصف قوس النهار فهو فضل الدائر وأثبتناه بحيال تلك المقنطرة للعرض المطلوب لرأس المنقلبين فإذا انتهت الغاية فاستخرج للحمل فاذا انتهت الغاية فاستخرج للثور وللجوزاء ولكوكب بعده بقدر عرض البلد

وأمّا السموت إن شئت أن تكون عشرة عشرة أو خمسة خمسة أو غير ذلك فاستخرج الارتفاع لقدر عدد السمت من الباب $\overline{\text{كه}}$ لرأس المنقلب المخالف لجهة عرض البلد من سعة مشرقه إلى $\overline{\text{ص}}$ وما كان أقلّ من سعة مشرقه استخرجه

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[1] لا حلا **MS** [2] Illegible word (looks like هب ... المـ) **MS** [3] أحدها **MS**

D:26r

جدول الأعداد المتناسبة لمصنف هذا الكتاب النصف منه				
عدد	الأول	الثاني	الثالث	الرابع
١٦	ارتفاع لا سمت له	جيب الميل أو جيب البعد	الجيب الأعظم	جيب عرض البلد
١٧	جيب عرض البلد	جيب الارتفاع لبدء زيادة السمت واتهاء نقصانه للأجزاء الشمالية عن سمت الرأس	جيب البعد	الجيب الأعظم
١٨	جيب تمام الارتفاع	جيب تمام الميل أو البعد	جيب فضل الدائر	جيب تمام السمت
١٩	جيب سعة المشرق والمغرب	جيب الميل أو جيب البعد	الجيب الأعظم	جيب تمام عرض البلد
٢٠	جيب سعة المشرق والمغرب	جيب نصف الفضلة	جيب تمام الميل أو جيب تمام البعد	جيب عرض البلد
٢١	الميل الموافق لعرض البلد وجهته	ميل درجة السامتة	واحد	واحد
٢٢	قطر ظل الزوال	يؤخذ بمثله من سهم نصف القوس فهو الفضل ما بين سهم نصف القوس وسهم فضل الدائر	قطر ظل الوقت منحطا	الجيب الأعظم
٢٣	جيب تمام ارتفاع درجة وسط سماء الطالع	جيب ما بين وسط السماء ووسط سماء الطالع †	الجيب الأعظم	جيب تمام سمت قطب فلك البروج
٢٤	جيب ما بين درجة العاشر والطالع بدرج السواء	جيب ارتفاع العاشر وهو جيب غاية المتوسط	الجيب الأعظم	جيب ارتفاع درجة وسط سماء الطالع وجيب تمام ارتفاع قطب فلك البروج
٢٥	جيب الميل أو جيب البعد	جيب ارتفاع قطب المدار	الجيب الأعظم	جيب عرض البلد
٢٦	جيب الأصل	فضل ما بين جيب ارتفاع القطر وجيب الغاية	الجيب الأعظم	سهم قوس ص
٢٧	جيب عرض الكوكب المعدل	جيب تمام الميل الثاني لدرجة طول الكوكب	جيب بعد الكوكب	جيب تمام الميل الأعظم
٢٨	جيب تمام عرض البلد منحطًا	جيب الأصل	الجيب الأعظم	جيب تمام الميل أو البعد منحطا
٢٩	جيب تعديل الدرجة أقرب من الاعتدالين بدرج السواء	ظل الميل الثاني منكوس	الجيب الأعظم	ظل الميل الأعظم منكوس
٣٠	جيب عرض البلد	جيب سعة المشرق	جيب تمام عرض البلد	جيب ارتفاع لا عرض له

† المطالع **MS**

D:25v

جدول الأعداد المتناسبة للشيخ أبي * علي المرّاكشي النصف منه **				
عدد	الأول	الثاني	الثالث	الرابع
١	جيب بعد الدرجة من أقرب رأس أحد الاعتدالين	جيب ميل الدرجة	الجيب الأعظم	جيب الميل الأعظم
٢	فضل ما بين الميل والعرض المتفقا في الجهة ومجموعهما إن اختلفا	تمام الغاية	واحد	واحد
٣	فضل ما بين تمام الغاية والميل المتفقا في جهة ومجموعهما إن اختلفا	عرض البلد	واحد	واحد
٤	جيب تمام غاية الدرجة	ظل الزوال مبسوطًا	جيب الغاية	أجزاء الشخص
٥	قطر الظل المبسوط	أجزاء الشخص	الجيب الأعظم	جيب الارتفاع
٦	ظل تمام الميل أو ظل تمام البعد مبسوط	جيب نصف الفضلة	ظل عرض البلد مبسوط	الجيب الأعظم
٧	جيب تمام الميل	جيب بعد الدرجة من أقرب رأس أحد المنقلبين بالدرج السواء	الجيب الأعظم	جيب تمام المطالع بالفلك من أقرب رأس أحد الاعتدالين ***
٨	جيب تمام عرض الكوكب	جيب مطالع الكوكب من المنقلب القريب منه	جيب تمام بعد الكوكب	جيب بعد درجت طوله من أقرب رأس أحد المنقلبين بالدرج السواء
٩	نصف مجموع جيب غاية الدرجة وغاية نظيرها	جيب الأصل	واحد	واحد
١٠	جيب الأصل	فصل ما بين الغاية وجيب ارتفاع الوقت	الجيب الأعظم	سهم فضل الدائر
١١	جيب الأصل	جيب الارتفاع المأخوذ	الجيب الأعظم	جيب الترتيب
١٢	جيب السمت	تعديل السمت وهو مجموع الحصة وجيب سعة المشرق أو الفضل بينهما	الجيب الأعظم	جيب تمام الارتفاع المأخوذ
١٣	جيب عرض البلد	جيب تمام عرض البلد	حصة السمت	جيب الارتفاع
١٤	جيب الأصل للجزء المسامت بمكة	فضل ما بين جيب الارتفاع المأخوذ وبين جيب غاية جزء المسامت بمكة	الجيب الأعظم	سهم فضل تفاضل الطولين إذا كان التفاضل أقل من نصف قوس نهار درجة المسامتة
١٥	جيب الأصل للجزء المسامت بمكة	فضل ما بين جيب الارتفاع المأخوذ وبين جيب غاية جزء المسامت بمكة	الجيب الأعظم	سهم فضل تفاضل الطولين إذا كان نصف القوس أكبر من فضل ما بين الطولين

* أبو **MS**

** Marginal note in a later hand: قُلتُ وليس ذلك للمراكشي كما قال وإنما ذلك للأقدمين

*** بالدرج السواء crossed-out.

[فائدة في جدول الأعداد المتناسبة]

بســــــم الله الرحمن الرحيــــم

D:25r **قـــال** الشيخ الإمام العالم مصنّف هذا الكتاب رضي الله عنه ومتع المسلمون ببقائه

نحتاج أن نذكر الدليل على صحّة الأبواب بطريق الحساب المذكور للمشايخ الفضلاء من أهل هذه العلم فوجدته بأسهل طريق وأقرب مأخذ مجدولًا منسوبًا إلى الشيخ الفاضل أبي[4] علي المرّاكشي رحمة الله عليه وهو الجدول المعروف بجداول النِسَب وهي سب عملًا بطول الجدول و د أعمال بعرض الجدول وذكر كلّ عمل في أحد البيوت الأربعة

وأمّا معرفة العمل به أن تضرب أحد الطرفين في الآخر فما حصل من الضرب تقسمه على أحد المتوسّطين فيخرج[5] أحد المتوسّطين أو تضرب أحد المتوسّطين في الآخر فما حصل من الضرب تقسمه على أحد الطرفين فيخرج[6] أحد الطرفين

بيان ذلك أن تضرب الأوّل في الرابع وتقسمه على الثالث فيخرج[7] الثاني أو تقسمه على الثاني فيخرج[8] الثالث أو تضرب الثاني في الثالث فما حصل من الضرب إن قسمته على الأوّل فخرج[9] الرابع وإن قسمته على الرابع فخرج[10] الأوّل فأخذت من الأبواب المنسوبة إلى الشيخ أبي[11] علي خمسة عشر بابًا وكملتها بخمسة عشر بابًا فكانت ثلاثون عملًا لإقامة الدليل على صحّة الأبواب المتقدّمة وهي مائة خمسة وعشرون بابًا فهذه ل يستخرج منها صب[12] بابًا ويبقى له لا يحتاج شيئًا فإنّها مشروحة مبيّنة من أبوابها والله أعلم بالغيب[13] <و> أحكم وهو هذا الجدول الذي في ظهر هذه الورقة وصلى الله على سيدنا محمد وآله وصحبه وسلم

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4 أبو MS 5 يخرج MS 6 يخرج MS 7 يخرج MS 8 يخرج MS 9 خرج MS 10 خرج MS 11 أبو MS 12 Should be صَ 13 بالغيب] نغيب MS

D:24v

جـــــــــــدول الأبعاد والتعاديل

البعد	تعديل الكوكب ج	ق	ي	ث	البعد	تعديل الكوكب ج	ق	ي	ث	البعد	تعديل الكوكب ج	ق	ي	ث
ا	ۮ	ه	يد	يه	لا	ج	ۮ	يه	يا	سا	ط	ا	ل	ج
ب	ۮ	ي	كح	يح	لب	ج	ز	كز	لا	سب	ط	كج	يز	ي
ج	ۮ	يه	مب	كب	لج	ج	يد	مط	ي	سج	ط	مح	كا	ب
د	ۮ	ك	يو	ۮ	لد	ج	كب	ل	يز	سد	ي	يه	يج	د
ه	ۮ	كو	ط	كب	له	ج	ل	كح	ز	سه	ي	مد	لد	و
و	ۮ	لا	كب	ي	لو	ج	لز	يز	مو	سو	يا	يه	يد	يه
ز	ۮ	لو	لد	ل	لز	ج	مو	د	ب	سز	يا	مح	يط	ي
ح	ۮ	ما	مو	ا	لح	ج	نج	نو	له	سح	يب	كج	ك	ح
ط	ۮ	مو	نو	مز	لط	د	ب	يه	مه	سط	يج	ا	يا	كط
ي	ۮ	نب	و	نه	م	د	يب	ه	ب	ع	يج	مج	ب	مز
يا	ۮ	نح	مد	لد	ما	د	كا	يو	يح	عا	يد	ل	ج	يط
يب	ا	ج	نط	يج	مب	د	ل	كو	نح	عب	يه	كد	ب	م
يج	ا	يا	يه	كه	مج	د	لط	لح	نح	عج	يو	كب	يز	ل
يد	ا	يد	ن	يا	مد	د	مط	مط	يط	عد	يز	كز	ط	ز
يه	ا	ك	كد	مز	مه	ه	ۮ	ۮ	ۮ	عه	يح	م	ه	ب
يو	ا	كو	ا	كد	مو	ه	ي	ي	ج	عو	ك	د	يب	ا
يز	ا	لا	ج	ي	مز	ه	ك	كط	ه	عز	كا	م	كا	ط
يح	ا	لو	ۮ	يا	مح	ه	لا	لا	د	عح	كج	لب	م	و
يط	ا	مب	ا	يد	مط	ه	مج	كه	ح	عط	كه	مد	لط	م
ك	ا	مح	يد	كا	ن	ه	نو	يط	مه	ف	كح	كا	ك	ب
كا	ا	ند	يط	ند	نا	و	ي	كد	د	فا	لا	لد	يح	ا
كب	ب	ۮ	لو	كب	نب	و	كد	ج	ط	فب	له	له	ج	و
كج	ب	ز	يه	كا	نج	و	لح	مب	يز	فج	م	مج	ك	ي
كد	ب	يج	لو	مه	ند	و	نج	كه	ه	فد	مز	لد	يا	ح
كه	ب	يط	يج	لا	نه	ز	ح	كز	ۮ	فه	نز	ح	م	ب
كو	ب	كو	يط	يط	نو	ز	كد	مد	يح	فو	عا	لد	يج	د
كز	ب	لب	يب	ح	نز	ز	ما	لا	لح	فز	صو	ا	يز	ك
كح	ب	لط	لا	ي	نح	ح	ۮ	ب	ج	فح	قما	كز	كا	م
كط	ب	مو	يج	و	نط	ح	يط	م	يط	فط	رفه	ج	يط	كد
ل	ب	نج	يز	نب	س	ح	لط	لد	ي	ص	*			

* هو قطب معدل النهار لا يمكن أن يكون كوكبًا

[خاتمة القسم الأوّل]

D:24r **قـــال** الشيخ رضي الله عنه **تمّت أبواب الأعمال** بعون الله ذي الجلال

وقد جعلتُها مائة وثلثين بابًا منها مائة سبعة وعشرون ليس فيها ضربًا ولا قسمة ولا جذر ولا نسبة وكلّها محتالة على الجداول وثلاثة أبواب فيها الضرب والقسمة والنسبة وما جعلتها مع الأبواب إلّا لكون ألّا غناء عنها وأكثر استخراجها يحتال على الجداول والبابين أوّلهما في الباب المائة وسبعة عشر وآخرها المائة وعشرون والباب الثالث في الثامن والعشرون ومائة ولم أذكرها في كتابي هذا إلّا لكون أنّها يحتاج إليها وقد صنّفتها من غير أن أطلّع على أبوابها ولم أعلم أحدًا ذكرها في عصرنا هذا فلذلك ذكرتها في كتابي

ولفتّ إلى الضرب والقسمة والنسبة المذكورة فمن وقف عليه فليُسامِحنا عمّا ذكرناه من طريق الضرب والقسمة والنسبة لأجل هذه الأبواب خاصّة والله الموفّق للصواب

يتلوه جدول الأبعاد والتعاديل إن شاء الله تعالى وحسبنا الله ونعم الوكيل

الباب الآخر من القسم الأوّل في العمل بجداول الدائر وخاتمتها

D:24r

البــــــاب الثلاثون ومائة في معرفة أنصاف أقطار المقنطرات والمدارات

خذ الفضل بين عدد المقنطرة وعرض البلد وخذ ظلّ نصفه منكوسًا[1] <و> احفظه إن أردت نصف القطر الأقرب إلى القطب واجمعهما إن أردت نصف القطر الأبعد وخذ نصف ما اجتمع <و> احفظه ثم خذ ظلّه مبسوطًا من جدول الظلّ وزد على كلّ منهما ثلثيه فما اجتمع انقص <منه> لكلّ درجة دقيقة فما بقي فهو نصف القطر المطلوب فإن كان مجموعهما أكثر من ص فاسقط مجموعهما من قف فما بقي خذ ظلّ نصفه منكوسًا وزد عليه ثلثيه كما فعلت أوّلًا فإن شئت أن تجعله جدولًا وتضع به المقنطرات على أنّ نصف قطر الصفيحة ل هذا في البسط الشمالي وبالعكس من ذلك في الجنوبي

فإن أردت دائرة أوّل السموت فزد عرض البلد[2] على ص وخذ ظلّ نصف المجموع منكوسًا[3] واحفظه ثم انقص عرض البلد من ص فما بقي خذ ظلّ نصفه منكوسًا واحفظه وزد على كلّ محفوظ منهما ثلثيه فما اجتمع انقص <منه> لكلّ درجة دقيقة فما حصل فهو نصف القطر الأقرب والأبعد فاجمع الأقرب والأبعد وخذ نصف مجموعهما فهو بعد مركز دائرة أوّل السموت من القطب

<طريق آخر :> وإن شئت فاجمع ظلّ نصف ارتفاع الحمل مبسوطًا ومنكوسًا فما اجتمع زد عليه ثلثيه وانقص <منه> لكلّ درجةٍ دقيقة فما بقي وهو بعد مركز دائرة أوّل السموت والله أعلم

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1 MS منكوس 2 عرض البلد] MS تمام عرض البلد 3 MS منكوس

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كتاب في الآلات الفلكيّة

تأليف

نجم الدين أبي عبد الله محمد بن محمد المصري

حقّقه وترجمه وفسّره

فرانسوا شاريت

دار بريل للنشر

بمدينة ليدن المحروسة

سنة ١٤٢٤ هـ / ٢٠٠٣ م